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CONFERENCE OF EMPIRE METEOROLOGISTS, 1929.

AGRICULTURAL SECTION.

Crop Forecasting and the Use of Meteorological Data in its Improvement.

IMPERIAL BUREAU OF MYCOLOGY 1930

LONDON:
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Rothamsted Experimental Station.

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I.—REVIEW OF WORK SO FAR ACCOMPLISHED.

1. A.—INTRODUCTORY.

The forecasting of crop yields has been practised for many years by Government Departments throughout the world. These official forecasts nearly all follow a similar procedure. The Departments secure from large numbers of crop reporters or estimators, distributed throughout the agricultural area, their estimates of probable outturn expressed in some numerical form.

Official forecasts depend mainly upon the crop reporters' inspection of the growing crop, which they supplement from their experience of the general effect upon the crop yields of the weather conditions in which the crop has been sown and grown. These forecasts may or may not be checked or supplemented by other reports or calculations.

This method is subjective, depending as it does upon judgments, and since the beginning of the century, or even before, a considerable literature has grown up on investigations, scientific (and otherwise), having as their aim the determination of an objective method of forecasting to supplement the subjective method.

These have nearly all looked to the weather as providing the objective basis, but a study of the literature on the relation between weather and crops soon reveals that, although much progress has been made, the problem of forecasting crops wholly or partly on the basis of the weather is by no means solved.

There have been two main lines of research which have attracted the attention of trained scientific men and others in the investigation of the conditions which induce good and bad crops, and in the establishment of relations which will provide data whereon to base forecasts of the ultimate yield. These two lines are, firstly, the determination of a cycle, or regular sequence, of a definite number of years at the end of which similar meteorological and, as a consequence, agricultural phenomena are reproduced; and, secondly, the ascertainment of the effects of different types of weather during or shortly before the growing period of the crop. The two lines of enquiry are not, of course, mutually exclusive.

Before tracing the history of these enquiries it may be well to consider in a little more detail the methods at present in practical use. It will be necessary to consider not only forecasts of yields and of acreage, but estimates of acreage made after sowing and of yields made after harvest, since such estimated yields must form the basis of future research on crop forecasting. Indeed, if final estimates are inaccurate, forecasts are guesses at a riddle whose answer is unknown.

1. B.—METHODS AT PRESENT IN USE.

(i) ENGLAND AND WALES.—In England the system of the Ministry of Agriculture and Fisheries is to obtain monthly reports from local reporters (who numbered 220 up to 1918, and have since numbered about 320). In addition to descriptive information, the reporters give for their respective districts on the 1st January the approximate area sown with each crop up to that time, expressed as a percentage increase or decrease on the corresponding area sown at the same date in the previous year. On the 1st June they again give the approximate area under each crop, expressed as a percentage of the previous year's area, and also an estimate of the total area under each crop in acres.

The reporters are also responsible for obtaining for each parish in their district a return from every occupier of an "agricultural holding." These returns are, under the Agricultural Returns Act, 1925, compulsory for all holdings exceeding one imperial acre of land used for the production of crops or for grazing. These returns include among other information the acreage of the different crops on the holding on the 4th June, and from such returns the acreage under each crop is obtained for each parish. On the 1st July the reporters give a forecast of the yield of wheat, barley, oats, beans, peas and potatoes, expressed as a percentage of the last ten years' average, in their respective districts, and of "seeds" hay and meadow hay in cwts. per acre.

On the 1st of August they give a forecast of the yields of wheat, barley, oats, beans, peas and "seeds" and meadow hay in cwts. per acre, and of potatoes, turnips and swedes, mangolds and sugar beet as a percentage of the previous ten years' yield in their respective districts.

On the 1st September a revised forecast is given for cereals, beans, peas and hay in cwts. per acre, for potatoes in tons per acre, and for turnips and swedes, mangolds and sugar beet as a percentage of the previous ten years' yields in their respective districts.

On the 1st October a further forecast is given for cereals, beans and peas in cwts. per acre, and for all root crops in tons per acre.

On the 1st November a revised forecast is again given for the root crops, also an average estimate of the yield of wheat, barley and oat straw in each district in cwts. per acre, and of the average weight of grain per Imperial bushel (lbs. per bushel) for wheat, barley, oats, beans and peas.

All these forecasts are for each reporter's district as a whole, but on the 15th November each reporter sends in to the Ministry a return giving separately for each parish in his district the estimated yield per acre (cwts. per acre in the case of cereals, beans, peas and hay, and tons per acre in the case of roots). The estimated yield in a parish is multiplied by the acreage under the crop in that parish as returned by the occupier on the 4th June, and from these parish

totals the production of each county and the country as a whole is obtained.

The estimates of acreage sent in by the reporters on the 1st June are used by the Ministry as a basis for the statement on acreage made in their published monthly agricultural report dated June 1st. This statement is made in general terms, e.g., " From estimates made by the crop reporters it would appear that the total acreage under wheat in England and Wales (in 1928) is somewhat less than in 1927, while the acreage of barley is about the same, and that of oats slightly increased." A forecast of the yield of " seeds " and meadow hay for the whole country as a percentage of the average is published in the report dated June 1st.

In the Ministry's report dated July 1st the reporters' figures of July 1st are utilised in a similar manner. Forecasts of yields of cereal crops and of hops are given in general terms or as a percentage figure, and of seeds and meadow hay, for the whole country, in cwts. per acre.

In the Ministry's report dated August 1st a revised estimate of the hay yield for the whole country is given and a forecast of the yields of wheat, barley and oats in cwts. per acre for each of the main districts of England and Wales and for the whole country, also a forecast of the yield of beans and peas for the whole country. The Department of Agriculture for Scotland, however, gives only a percentage figure. Yields of roots are forecasted by main districts in general terms, e.g., average, above average, or below average, and the same applies to hops.

In the Ministry's report dated September 1st a revised forecast for wheat, barley and oats for the main districts of England and Wales and for the whole country is given in cwts. per acre; also of beans and peas and hops for the whole country. In addition the acreage of these three cereal crops and a forecast of total production in tons for the whole country are given. A forecast in tons per acre for potatoes is given for the whole of England and Wales and for the main districts in general terms. Root crops are also forecasted for the main districts in general terms.

In the Ministry's report dated October 1st revised forecasts for wheat, barley and oats for the main districts of England and Wales and for the whole country are given in cwts. per acre. Similar forecasts in tons per acre are now given for potatoes, for turnips and swedes, and for mangolds. The acreage and a revised forecast of the total production of wheat, barley and oats for the whole country are again given and a similar forecast for potatoes, turnips and swedes, and mangolds is now added.

In the Ministry's report dated November 1st revised forecasts of the yield of potatoes, turnips and swedes, and mangolds in tons per acre are given. The forecasts of total production of root crops are also revised.

The final estimates based on the crop reporters' final figures of the 15th November are published in the Annual "Agricultural Statistics" and are not available until early in the following year.

In Tables I–X is given a comparison between the forecasted yields and the final estimates for 10 principal crops in England and Wales.

TABLE I.

Wheat—England and Wales.

Year.	Forecast of Yield—cwts. per acre.						Final Estimate.
	Aug. 1st.		Sept. 1st.		Oct. 1st.		
	Yield.	Per cent. Diff. from Final.	Yield.	Per cent. Diff. from Final.	Yield.	Per cent. Diff. from Final.	
1923	17·6	+0·6	17·5	0·0	17·2	−1·7	17·5
1924	17·5	−0·6	17·5	−0·6	17·6	0·0	17·6
1925	17·1	−5·4	17·4	−3·9	17·6	−2·8	18·1
1926	18·0	+9·8	17·7	+7·9	16·7	+1·8	16·4
1927	17·0	−2·3	17·0	−2·3	17·0	−2·3	17·4
1928	17·25	−5·2	17·4	−4·4	17·7	−2·7	18·2
Mean Diff. per cent.	—	−0·5	—	−0·5	—	−1·3	—
Estimated S.D.*	—	5·6	—	4·5	—	1·9	—

* The term "estimated S.D." has been used to mean $\sqrt{\frac{S(x-\bar{x})^2}{n-1}}$ since "S.D." by itself might be taken as $\sqrt{\frac{S(x-\bar{x})^2}{n}}$. In the terminology of sampling, the former is the best estimate of the population S.D. that may be obtained from the sample.

TABLE II.

Barley—England and Wales.

Year.	Forecast of Yield—cwts. per acre.						Final Estimate.
	Aug. 1st.		Sept. 1st.		Oct. 1st.		
	Yield.	Per cent. Diff. from Final.	Yield	Per cent. Diff. from Final.	Yield.	Per cent. Diff. from Final.	
1923	14·3	−1·4	14·4	−0·7	14·1	−2·8	14·5
1924	15·1	−1·9	15·25	−1·0	15·2	−1·3	15·4
1925	14·0	−8·5	14·4	−5·9	14·3	−6·5	15·3
1926	16·0	0·0	16·5	+3·1	16·3	+1·9	16·0
1927	15·5	−6·1	15·7	−4·8	15·8	−4·2	16·5
1928	15·75	−8·4	16·2	−5·8	16·7	−2·9	17·2
Mean Diff. per cent.	—	−4·4	—	−2·5	—	−2·6	—
Estimated S.D.	—	3·7	—	3·7	—	3·1	—

Table III.

Oats—England and Wales.

Year.	Forecast of Yield—cwts. per acre.						Final Estimate.
	Aug. 1st.		Sept. 1st.		Oct. 1st.		
	Yield.	Per cent. Diff. from Final.	Yield.	Per cent. Diff. from Final.	Yield.	Per cent. Diff. from Final.	
1923	13·4	−2·2	13·4	−2·2	13·2	−3·6	13·7
1924	13·8	−6·1	14·0	−4·8	13·8	−6·1	14·7
1925	13·5	−8·8	13·5	−8·8	13·6	−8·1	14·8
1926	15·67	−2·1	16·0	0·0	16·1	+0·6	16·0
1927	15·33	+0·2	15·1	−1·3	14·8	−3·3	15·3
1928	15·4	−6·1	15·5	−5·5	15·8	−4·8	16·4
Mean Diff. per cent.	—	−4·2	—	−3·8	—	−4·2	—
Estimated S.D.	—	3·4	—	3·2	—	3·0	—

Table IV.

Beans—England and Wales.

Year.	Forecast of Yield—cwts. per acre.						Final Estimate.
	Aug. 1st.		Sept. 1st.		Oct. 1st.		
	Yield.	Per cent. Diff. from Final.	Yield.	Per cent. Diff. from Final.	Yield.	Per cent. Diff. from Final.	
1923	16·5	−2·9	16·25	−4·4	16·75	−1·5	17·0
1924	16·2	−1·2	16·2	−1·2	16·3	−0·6	16·4
1925	16·75	−5·4	16·7	−5·6	17·0	−4·0	17·7
1926	14·75	−6·1	14·7	−6·4	14·9	−5·1	15·7
1927	16·75	−2·6	16·5	−4·1	16·5	−4·1	17·2
1928	16·33	−1·6	16·0	−3·6	16·3	−1·8	16·6
Mean Diff. per cent.	—	−3·3	—	−4·2	—	−2·8	—
Estimated S.D.	—	2·0	—	1·8	—	1·8	—

Table V.

Peas—England and Wales.

Year.	Forecast of Yield—cwts. per acre.						Final Estimate.
	Aug. 1st.		Sept. 1st.		Oct. 1st.		
	Yield.	Per cent. Diff. from Final.	Yield.	Per cent. Diff. from Final.	Yield.	Per cent. Diff. from Final.	
1923	14·5	+1·4	14·25	−0·3	14·25	−0·3	14·3
1924	15·1	+2·0	14·7	−0·7	14·8	0·0	14·8
1925	13·25	−2·4	13·5	−7·5	13·75	−5·8	14·6
1926	14·5	−0·7	14·6	0·0	14·8	+1·4	14·6
1927	14·75	+11·7	14·0	+6·1	17·0	+6·1	13·2
1928	—	—	15·0	−5·7	15·3	−3·8	15·9
Mean Diff. per cent.	—	+2·5 (5 years)		−1·3	—	−0·4	—
Estimated S.D.	—	5·4	—	4·8	—	4·2	—

Table VI.

Seeds Hay—England and Wales.

Year.	Forecast of Yield—cwts. per acre.						Final Estimate.
	July 1st.		Aug. 1st.		Sept. 1st.		
	Yield.	Per cent. Diff. from Final.	Yield.	Per cent. Diff. from Final.	Yield.	Per cent. Diff. from Final.	
1923	29·5	−5·4	31·75	+1·8	32·0	+0·8	31·2
1924	31·5	−0·9	33·00	+3·8	33·0	+1·2	31·8
1925	29·5	−1·0	30·0	+0·7	—	—	29·8
1926	29·0	−2·7	30·25	+1·5	—	—	29·8
1927	23·75	−10·3	25·33	−4·4	25·5	−1·0	26·5
1928	26·25	−3·8	26·5	−2·9	26·7	−0·6	27·3
Mean Diff. per cent.	—	−4·0	—	+0·1	—	+0·1 (4 years)	
Estimated S.D.	—	3·5	—	3·1	—	1·0	

Table VII.

Meadow Hay—England and Wales.

Year.	Forecast of Yield—cwts. per acre.						Final Estimate.
	July 1st.		Aug. 1st.		Sept. 1st.		
	Yield.	Per cent. Diff. from Final.	Yield.	Per cent. Diff. from Final.	Yield.	Per cent. Diff. from Final.	
1923	20·0	−10·7	21·75	−2·9	22·0	−1·8	22·4
1924	22·5	−3·0	23·5	+1·3	23·25	+0·2	23·2
1925	20·0	−5·2	20·5	−2·8	—	—	21·1
1926	20·75	−5·3	21·5	−1·8	—	—	21·9
1927	16·5	−14·1	18·0	−6·2	18·0	−6·2	19·2
1928	18·25	−3·9	18·33	−3·5	18·5	−2·6	19·0
Mean Diff. per cent.	—	−7·0	—	−2·7	—	−2·6 (4 years)	
Estimated S.D.	—	4·4	—	2·4	—	2·7	

Root Crops.

Table VIII.

Potatoes—England and Wales.

Year.	Forecast of Yield—tons per acre.						Final Estimate.
	Sept. 1st.		Oct. 1st.		Nov. 1st.		
	Yield.	Per cent. Diff. from Final.	Yield.	Per cent. Diff. from Final.	Yield.	Per cent. Diff. from Final.	
1923	5·6	−5·1	5·7	−3·4	5·7	−3·4	5·9
1924	5·8	−3·3	6·2	+3·3	5·8	−3·3	6·0
1925	5·8	−10·8	6·0	−7·7	6·2	−4·6	6·5
1926	5·7	+3·6	5·5	0·0	5·4	−1·8	5·5
1927	5·8	−3·3	5·8	−3·3	5·8	−3·3	6·0
1928	6·1	−16·4	6·5	−11·0	6·75	−7·5	7·3
Mean Diff. per cent.	—	−5·9	—	−3·7	—	−4·0	—
Estimated S.D.	—	6·9	—	5·1	—	2·0	—

TABLE IX.

Turnips and Swedes.

Year.	Forecast of Yields—tons per acre.				Final Estimate.
	Oct. 1st.		Nov. 1st.		
	Yield.	Per cent. Diff. from Final.	Yield.	Per cent. Diff. from Final.	
1923 ..	12·6	−0·8	12·7	0·0	12·7
1924 ..	12·4	−1·1	13·8	−0·6	13·9
1925 ..	11·2	−1·8	11·0	−3·5	11·4
1926 ..	14·2	−1·4	14·5	+0·7	14·4
1927 ..	12·0	−1·6	12·0	−1·6	12·2
1928 ..	13·2	−4·3	13·7	−0·7	13·8
Mean Diff. per cent. ..	—	−1·8	—	−1·0	—
Estimated S.D.	—	1·2	—	1·4	—

TABLE X.

Mangolds—England and Wales.

Year.	Forecast of Yields—tons per acre.				Final Estimate.
	Oct. 1st.		Nov. 1st.		
	Yield.	Per cent. Diff. from Final.	Yield.	Per cent. Diff. from Final.	
1923 ..	17·0	−1·7	17·3	0·0	17·3
1924 ..	19·2	−5·0	19·7	−2·5	20·2
1925 ..	19·4	−2·5	19·5	−2·0	19·9
1926 ..	20·2	−4·3	20·5	−2·8	21·1
1927 ..	17·6	−1·7	17·7	−1·1	17·9
1928 ..	18·5	−4·1	18·9	−2·1	19·3
Mean Diff. per cent. ..	—	−3·2	—	−1·7	—
Estimated S.D.	—	1·4	—	1·0	—

It will be noticed that there is a marked tendency for forecasts to be below the final estimates, perhaps due to the proverbial pessimism of the farmer. The only cases in which the mean of the differences between the forecast and the final estimate are positive are those of the August and September forecasts of " seeds " hay and these are not significantly different from zero statistically.

Of the cereal forecasts that of wheat seems to have the least bias, but rather less precision in the August and September forecasts and rather more in the October forecast than barley and oats. These results are, however, barely significant statistically. The bean forecasts appear to be more biassed but also more precise than those of peas. The difference as regards bias is barely significant but that as regards precision is significant. Potato forecasts exhibit more bias and less precision than those of turnips and swedes or mangolds, the forecasts of the latter two crops being decidedly good. Here again the difference as regards bias is barely significant, but that as regards precision is significant.

A comparison between forecasts and final estimates, however, tells us nothing about the accuracy of the final estimates themselves and some research into this question would be of great value.

As a preliminary enquiry of this nature, the final estimates of the yields of wheat in Great Britain and Hertfordshire over the 30 years 1893–1922 were taken from the Official Statistics and compared with the yields on the farmyard-manure plot of Broadbalk field at Rothamsted (ascertained by actual weighings) over the same years. The figures are as follows :—

TABLE XI.

Year.	Great Britain. Bushels per acre.	Herts. Bushels per acre.	Broadbalk. Bushels per acre.
1893	25·95	23·96	34·25
4	30·69	31·73	45·44
5	26·23	26·59	43·88
6	33·68	33·58	43·94
7	29·08	28·88	37·25
8	34·74	34·18	38·00
9	32·75	33·61	42·50
1900	28·53	27·32	32·25
1	30·84	30·89	39·62
2	32·83	31·90	41·53
3	30·13	28·18	29·69
4	26·82	23·21	22·27
5	32·78	31·03	38·51
6	33·66	34·69	43·56
7	33·96	34·75	36·15
8	32·29	30·12	39·78
9	33·69	32·63	33·83
1910	30·34	27·63	29·14
1	32·9	32·03	36·70
2	29·0	28·58	18·13
3	31·5	31·25	22·18
4	32·7	31·01	30·39
5	31·5	28·83	35·11
6	28·8	24·29	27·25
7	30·2	28·92	16·47
8	33·2	32·3	25·27
9	29·1	26·0	28·03
1920	28·7	30·2	31·83
1	35·4	34·2	26·71
2	31·4	30·6	32·71

The means and estimated standard deviation are given below in Table XII.

TABLE XII.

——	Great Britain.	Herts.	Broadbalk.
Mean Yield 1893–1922 (bushels per acre)	31·11	30·10	33·41
Estimated S.D.* (bushels per acre)	2·50	3·20	7·82
Per cent. of Mean	8·0	10·6	23·4

It will be seen that the percentage variation is somewhat less for Great Britain than for Hertfordshire, but the variances for these two areas are not significantly different ($Z = \cdot2469$, with 29 degrees of freedom, the 5 per cent. point is ·2994). The yields on Broadbalk were, however, altogether more variable.

As there is a marked downward trend of yields on Broadbalk all three series were examined for trend.

No significant trend was found for Great Britain or for Hertfordshire, but in the case of Broadbalk, after eliminating the trend (which for these 30 years did not depart significantly from linearity) the estimated S.D. was reduced to 6·20 bushels per acre or 18·6 per cent. Thus after eliminating trend the variation on Broadbalk remained very markedly larger than in the other two cases.

This, as far as it goes, would seem to indicate that crop reporters tend to give estimates which both in good and bad years are too near the average. It must however be remembered that the area of the plot in question on Broadbalk is only $\frac{6}{20}$ of an acre, while the area under wheat in Hertfordshire is about 48,000, and that in Great Britain about 1,600,000 acres. Thus the area under wheat in Hertfordshire is about 160,000 times the area of the plot on Broadbalk, while the area under wheat in Great Britain is about 35 times that under wheat in Hertfordshire. Thus a bigger drop in variation might be expected from Broadbalk to Hertfordshire than from Hertfordshire to Great Britain, and there is some indication of a drop from Hertfordshire to Great Britain, though this drop is not significant on the data. On the other hand it should be noted that the least variable plot on the field has been used, and that the average of the whole field is probably not less variable ; while the meteorological differences experienced from year to year must be much more highly correlated for Hertfordshire than for England as a whole. Therefore, while there is a strong indication of a tendency on the part of crop reporters to be too near the average, this cannot, on the evidence here considered, be regarded as absolutely conclusive.

* *See* footnote to Table I.

(ii) The United States.—In the United States monthly crop reports have been issued since the organisation of the U.S. Department of Agriculture in 1862, but the re-organisation of the field-service as it is now constituted and the bringing of the personnel under the classified civil service did not take place until 1912–13–14. The description of the U.S. official system which follows is largely based on some lectures delivered to the New York State College of Agriculture in 1924 by W. F. Callander, Statistician-in-Charge of the Division of Crop and Livestock Estimates, which is the part of the Bureau of Agricultural Economics now responsible for carrying out the work.

Organisation.—Its personnel in Washington consists of a statistician-in-charge, a staff of eight or ten experienced statisticians and a corps of statistical clerks, numbering about 120. In the field the force consists of an agricultural statistician in each State or group of States and in the larger States an assistant agricultural statistician, numbering in all about sixty statisticians and sixty field clerks. These agricultural statisticians are in the classified Civil Service and are appointed only after passing a rigid Civil Service examination to test their educational and statistical qualifications.

Before taking the Civil Service examination each must show that he has had at least three years' practical experience in farming, and an education equivalent to a four years' course in an agricultural college, as well as some statistical training.

Each agricultural statistician enlists the voluntary services of from 250 to 300 selected crop correspondents, designated "aids," who report to him every month regarding the crops grown in the State.

One of the duties of the branch State offices (of the U.S. Department of Agriculture) is to accumulate for record, study and comparison all data available, relating to the statistics of agricultural production in the respective States. Each office (there were 42 in 1924) issues a monthly State crop report. In twenty-six States the branch offices are co-operating with the State Departments of Agriculture; in fact there is no State in the Union issuing systematic crop reports which does not co-operate with the U.S. Department of Agriculture. In a number of States, as in New York, the agricultural statistician is chief of the State Bureau or Division of Statistics.

In addition to the salaried agricultural statisticians and crop specialists, the crop reporting work has the co-operation of over 300,000 voluntary crop reporters, mostly farmers.

The farmer voluntary crop reporters contribute data for their localities and the Bureau of Agricultural Economics tabulates and summarises such data in the form of official Government crop reports

by each State, and the United States at large. The principal classes of reporters are :—

(1) The township reporters, comprising one farmer reporter for each agricultural township in the United States, who number slightly less than 30,000. Each township reporter reports monthly for the crops and livestock in his neighbourhood, using printed schedules, which, after being filled in, are mailed directly to Washington and are tabulated and summarised separately from all others.

(2) The county reporters, one for each agricultural county in the United States, number about 2,800. They report monthly upon all crops and classes of livestock for the entire county as a unit, basing their reports upon personal observation and enquiry and upon the written reports of other farmers, who report to them on printed schedules. The reports of the county reporters come directly to the Washington office, and are tabulated separately from all others.

In arriving at State averages the county reports are weighted, that is, each county is given a weight in the State proportionate to its relative production, so that a county producing four times as much of a given crop as another county has four times the importance of the latter county in determining the average. The county reporters are frequently utilised to obtain special information in addition to the regular monthly crop reports.

(3) Field aids, of whom there are more than 30,000, are voluntary reporters who report the agricultural conditions within their observation and knowledge monthly, forwarding their schedules to the *State agricultural statisticians*.

(4) Special price reporters, numbering about 18,000, report monthly to the *agricultural statisticians in their States* the prices received by farmers for their produce or paid by them for seed, feed, machinery, fertilisers, and other equipment and supplies. They are mostly local merchants and dealers.

(5) The livestock reporters, about 30,000 in number, report monthly directly to the Washington Office of the Bureau of Agricultural Economics upon one or more classes of livestock. They are selected because of their personal and financial interest in growing livestock and their special knowledge of livestock conditions.

(6) Mill and elevator reporters report directly to Washington on stocks of grain on hand on a particular date. There are about 22,000 of these reporters.

(7) Individual farm reporters numbering in excess of 70,000 report only for their own farms the actual number of acres grown under each crop, and the number of each class of livestock on the farm. These reports are made once or twice a year. They constitute an actual farm census for the individual farms and, to the extent that these farms are representative of all other farms, they serve as a valuable index of the changes that take place in crop acreages and livestock from one year to another.

In addition to the foregoing, several special lists, numbering several thousands, are maintained of crop reporters who report on special crops, such as cotton, tobacco, rice, potatoes, peanuts, fruit crops, etc., directly to Division headquarters in Washington for the particular crop in which they are interested and concerning which they are regarded as the best source of information.

It has been thought of interest to give the list in its entirety; it must, however, be remembered that the question of livestock lies outside the scope of this paper.

Information Provided.—Among the most important information provided by the Government crop reports are annual reports by States and by the U.S. Government of acreages planted to different crops, estimates of the growing crops as a percentage of the normal, forecasts of yield per acre and total prospective production during the growing season, yields per acre and total production at or near harvest time and much other information concerning movement of produce, stocks at mills and elevators, number and condition of different classes of livestock, progress of farm work, prices and other items which do not concern us in this study.

The U.S. Government crop-reports are in general issued monthly during the growing season, the cotton report, however, being on a different day from the report on other crops and fortnightly during the more critical period. In 1927 reports on acreage, condition and yield of cotton were published on July 6th, August 8th, September 8th, September 23rd, October 8th, October 25th, November 8th and December 8th. The date and hour of the publication of each report on all crops are decided a year in advance, and every possible measure is taken against information leaking out before the proper time. This is considered necessary owing to the effect such information would have on the state of the market.

The Crop Reporting Board.—"On crop reporting days," says Callander, "the Crop Reporting Board, which consists of the Chairman, three statisticians from the Washington Office and two or more statisticians from the field, assembles and carefully analyses all the data available for the monthly crop report. In a room adjoining that occupied by the Crop Reporting Board is assembled a force of expert statistical clerks and computers. For each crop a number of tabulation sheets is prepared, sufficient to supply each member of the Board with a copy. This sheet shows in parallel columns opposite each State: (1) the weighted average of the returns of the correspondents to the agricultural statisticians; (2) the individual estimate of the agricultural statistician for the State where it differs from the weighted average of his correspondents; (3) the weighted average of all the county reports for the State; (4) the weighted average of all the township reporters for the State; (5) the weighted average of the special reporters, if any, for the crop within the States; (6) the estimate of the Board for the previous month; (7) the estimate of the Board for the same crop

in the same State for the same date a year ago, and (8) the ten years average of the estimates of the Board for the same crop, State and date."

From these estimates each member of the Board then makes his own estimates of the final figure for the State independently of the other members of the Board, and then the Board discusses these estimates and arrives at a final figure. "As soon as the figures for a crop are determined by the Board for all the States in which it is grown, they are turned over to the computing section, and the necessary computations are made, such as converting percentage figures into equivalent concrete units, converting condition as a percentage of normal into its equivalent of prospective yields per acre for each State, and multiplying the estimated acreage by the indicated yield per acre to ascertain the probable total production of each State, and then combining State totals to ascertain totals and averages for the United States."

The work is then completed by multigraph-operators, and the reports are distributed, at the appointed hour, as expeditiously as possible.

Methods of Forecasting.—The methods of forecasting adopted must now be considered. As Callander admits: "Quantitative forecasting of the out-turn of crops months in advance of harvest, at least by official or governmental agencies, is of comparatively recent origin. It is confined as yet to a few countries. Forecasting was begun in the United States in 1912.

The technique or science of forecasting has not yet reached a very high degree of perfection, the methods used being largely empirical. Much has depended upon the personal judgment and intuition of the statisticians, but little having been done in the development of mathematical formulae. The field is broad and inviting to statisticians. Only a beginning of the development of a scientific technique has been made."

The problem of forecasting falls naturally into two main divisions, forecasting of acreages and forecasting of yield per acre.

Forecasting Acreage.—From the 'seventies until 1912 crop reporters were asked to estimate the acreage of each year's crops on the basis of the preceding year as 100 and this percentage method of comparison was mainly relied on by the Statistical Bureau in intercensal years. Each decennial census, of course, provided a new basis.

This method was naturally open to the objection that errors were cumulative, and about 1912 it was suggested that in addition correspondents should be asked to compare acreage this year with the acreage in a usual year, letting 100 represent the usual acreage. This comparison was included in all later acreage investigations, and was found to be a very useful addition, for dividing one year's percentage of usual by the preceding year's percentage of usual

gave an immediate check on the original comparison of one year based on the preceding year as 100;

Where changes were not large, this device was found very useful, but it was naturally of little value where there was a marked secular trend of acreage, up or down.

Since 1920 a number of more objective methods of forecasting or estimating acreage to supplement the percentage method have been tried, and according to Callander possess real merit.

The first is essentially a sampling process, reports being secured from a large number of individual farmers who report the acreages on their farms under each crop in the current and previous years. The data are grouped into four groups, according to size of farm, in order to avoid unduly weighting the large farms which preponderate in returns. Two methods can then be used. The current year's figure may be divided by the previous year's figure to obtain an estimated percentage increase in acreage under the particular crop, or alternatively the " ratio relative " of each year may be determined and that of the current year divided by that of the previous year to get an indicated percentage increase. The " ratio relative " in a particular year is the ratio of the area under a particular crop to that under all crops (or to all land in farms).

Both these methods present difficulties where the total land under crops is *not* substantially constant from year to year. Further, if the sample is too small, fluctuations of sampling present a difficult problem.

A second objective method, the " Field Count Method," consists in motoring along a selected territory regarded as typical of the area in question and counting the number of fields along the roadside under each crop, or as a refinement the number of telegraph poles.

A special speedometer has also been invented, having twelve special dials, one for each kind of crop, with a series of push buttons, which throws one of them into gear when needed. Thus the number of feet along the road under each kind of crop can be recorded in driving past.

Whichever method is adopted the " Field Counts " of two years provide data for obtaining an indicated percentage increase in a particular crop, while those of any one year may be used to obtain a " ratio relative " for any particular crop in that year.

Among other experiments photographic aeroplane surveys have also been attempted.

Forecasting Yield per Acre.—The method adopted is to obtain from reporters condition reports or estimates of the condition of the crop expressed in terms of the " normal " as 100. In instructions to reporters the term normal is described as follows :—" To begin with, a normal condition is not an average condition, but a condition above the average, giving promise of more than an average crop. Furthermore a normal condition does not indicate a perfect crop, or a crop that is or promises to be the very largest in quantity and

the very best in quality that the region reported on may be capable of producing.

The normal indicates something less than this, and thus comes between the average and the possible maximum, being greater than the former and less than the latter. The normal may be described as a condition of perfect healthfulness unimpaired by drought, hail, insects, or other injurious agency, and with such growth and development as may reasonably be looked for under these favourable conditions."

At the close of the season the reporters give their estimates of yield per acre. It is on the final estimates of yield per acre that the interpretation of the condition figures is based.

On dividing the estimated yield per acre by the condition figure for any area in any one month and multiplying by 100, what is known as the " par " for that month is obtained, i.e., the yield per acre which corresponds to a condition figure of 100.

It is found that the condition figure tends to fall throughout the growing season and the corresponding " pars " as a natural consequence, to rise.

The final " par " adopted for forecasting a given year is based on an inspection of the " pars " of preceding years, and of their five and ten years' moving averages, any secular trend being taken into account.

It is claimed that reporters understand the term normal ; quoting Callander again :—" The normal as used by the Department of Agriculture has been criticised by several eminent statisticians on the ground that it has no definite statistical basis, and, therefore, by itself cannot convey any meaning. It has been found, however, that the crop reporter has a well-defined judgment of what constitutes a normal for his locality. Moreover, the normal has been found to be a very stable figure. Representing the mean judgment of a multitude of observers, it adjusts itself slowly and naturally to any actual trend in yield per acre, such as might arise from the development of improved strains of higher yielding seed, the introduction of plant pests, such as the boll weevil, etc."

It is further claimed that the use of an " average " or a " fixed normal " of a given number of bushels per acre instead of the crop reporter's own conception of normal, would offer no advantages.

With this we are in agreement, since any bias would in any case be reflected in the resulting " pars."

The above remarks may be taken as applying to cereals and cotton, though in the latter case some special enquiries as to damage by boll weevil are also made ; but not to fruit for which a somewhat different and probably less accurate method of forecasting is adopted.

As an example of the degree of accuracy obtainable by the method described, the following table of forecasts of corn-production in Iowa compared with final estimated yields is given. It, of course, gives us no information about the accuracy of the final estimates.

TABLE XIII.

Corn—Iowa.

Year.	Forecasted Yield—Bushels per acre.								
	July.		August.		Sept.		Oct.		Nov.
	Yield.	Per cent. Diff. from Final.	Yield.	Per cent. Diff. from Final.	Yield.	Per cent. Diff. from Final.	Yield.	Per cent. Diff. from Final.	Final Estimate.
1914	39·5	+ 3·95	38·7	+ 1·84	35·6	−6·32	37·0	−2·63	38·0
1915	29·6	− 1·33	31·0	+ 3·33	28·9	−3·67	27·9	−7·00	30·0
1916	32·0	−12·33	36·1	− 1·10	36·9	+1·10	37·4	+2·47	36·5
1917	35·2	− 4·86	37·4	+ 1·08	36·9	−0·27	36·0	−2·70	37·0
1918	39·8	+10·56	40·4	+12·22	37·4	+3·89	37·4	+3·89	36·0
1919	35·7	−10·75	36·5	− 8·75	40·0	0·00	40·5	+1·25	40·0
1920	35·8	−12·70	40·4	− 6·70	40·5	−6·47	41·8	−3·46	43·3
1921	43·4	+ 3·33	39·7	− 5·48	41·6	−0·95	41·1	−2·14	42·0
1922	39·1	−13·11	40·9	− 9·11	42·7	−5·11	43·6	−3·11	45·0
Mean Diff. per cent	—	− 4·14	—	− 1·41	—	−1·98	—	−1·49	—
Estimated S.D.	—	8·73	—	5·47	—	3·60	—	3·39	—

It will be noted that in these figures, the early forecasts tend, on the whole, to be below the final estimate.

In addition to the above method, the Division of Crop and Livestock Estimates in conjunction with the U.S. Weather Bureau is experimenting with objective correlation methods having as their object the forecasting of crops from weather. In this connection work has been done by several private investigators, but the subject will be considered in the second section of this paper, to which it properly belongs.

(iii) INDIA.—In India crop forecasting possesses a special importance, because the land forms the basis of taxation. Largely as a result of the famine of 1877 the Department of Land Records and Agriculture was created about 1882, and its work, as far as obtaining data was concerned, for about 20 years consisted almost entirely of the collection of statistics, but crop cutting experiments were started in connection with settlement operations in 1893. From 1905–6 onwards the Departments of Land Records and Agriculture were separated, and it appears that their statistical functions were split up in a manner not entirely uniform from province to province. When the Montagu-Chelmsford reforms came, "Land Records" became a reserved Department, while

" Agriculture " was transferred, but in most provinces this had little effect on the actual system of collecting statistics.

The actual system of forecasting used bears certain resemblances to that of the United States. Reports are issued for wheat (3 reports), rice (in general, 3 reports), cotton (5 reports), linseed, rape, and mustard (3 reports), sesamum (3 reports, 2 in Bengal), groundnut (2 reports), jute (2 reports), indigo (2 reports), and sugar cane (3 reports). There is a report for each province and a resumé for each crop for all India.

There are three elements which must be considered separately in the formation of the forecast :—

(1) acreage.
(2) the standard or normal out-turn or yield per acre.
(3) the seasonal or condition figure.

As regards acreage the figures over the greater part of British India are better than in the United States, for the question of acreage is so intimately bound up with taxation that over the greater part of British India a detailed census of crops is taken every year and the results are tabulated. It is only in the " permanently settled " tracts that the absence either of a detailed survey or of sufficient land records staff, makes it impossible to record the areas under crops in such detail. It is perhaps worth while stating here that the permanently settled tracts, most of which are in Bengal (which is nearly all permanently settled) consist of estates which are taxed on a fixed assessment under a deed of permanent ownership granted by the state.

All reports contain estimates of acreage ; and as regards the final estimate the ultimate reporting unit is, in all non-permanently settled districts, the village. For keeping an account of the acreage under the various crops in these districts the village accountant is responsible. His records are inspected by the circle inspector, a circle consisting of four or five villages, and a statement, which the circle inspector usually signs as correct, is despatched to the sub-division of the district.

Here the sub-division officer makes totals for his sub-division which he sends on to the district officer, who in turn sends them on to the provincial Director of Agriculture ; or in some provinces the district totals are compiled in the Director's office.

As regards the earlier forecasts of acreage, reports are not always required from the village accountants, but the district forecasts are based on the reports of the sub-divisional officers, whose business it is to be thoroughly posted up at all times as regards the agricultural situation. This is the case in the Punjab and in the North-West Frontier Province, while in the United Provinces the estimates are made by selected landholders and officials such as supervisors.

In Bengal, which is permanently settled, and Bihar and Orissa, no revenue agency exists, and the figures are based on approximate estimates made by district officers which are more or less conjec-

tural. The district officers obtain information from the subdivisional officers through the agency of the police. As regards jute, however, in Bengal more accurate estimates are obtainable through the "*panchayats*" or village committees, while in Bihar and Orissa settlement operations have been completed in many districts and the settlement returns serve as a check on the estimates of acreage formed on the information furnished by the police.

It has been remarked that the acreage figures in British India are on the whole extraordinarily good ; there is, however, one important source of error in recording acreages—the existence of mixed crops. In a memorandum to the Indian Board of Agriculture in 1919 (ref. 1), G. A. D. Stuart, I.C.S., Officiating Agricultural Adviser to the Government of India, remarked: "Various methods of obviating this difficulty have been suggested, but the only method which appears to me to be of any value is that which has been adopted in the Central Provinces, where the area under each important mixture, such as cotton and *arhar* is entered separately in the Season and Crop Report (final estimate). There will thus be one column for pure cotton, a second column for pure *arhar*, and a third column for the usual cotton and *arhar* mixture.

Once the area under the mixture is correctly tabulated, it is a simple matter to estimate the yield of each constituent by applying suitable figures for average yield per acre and seasonal factor. These would, of course, differ from the corresponding figures for crops. When the most common standard mixtures have been tabulated separately, there would still remain over some area under miscellaneous mixtures.

If this area were of sufficient importance to warrant the adoption of any special method for taking it into account, I would do it as follows : Once in ten years make a very detailed census of actual crops by means of a special checking staff, specifying all mixtures in detail. Compare the figures so obtained with those reported by *patwaris* (village accountants) in the normal course. On the basis of this comparison the usual proportion of mixtures could be estimated and the reported figures of each year adjusted accordingly."

The Standard or Normal Out-turn.—The term normal has a different significance in India from that in the United States. According to Findlay Shirras (2) the most generally accepted definition is " that crop which past experience has shown to be the most generally recurring crop in a series of years, the typical crop of the local area, the crop which the cultivator has a right (as it were) to expect, and with which he is (or should be) content, while if he gets more he has reason to rejoice, and if less he has reason to complain. Briefly it is stated to be the average yield on average soil in a year of average character. This normal or average yield will not necessarily correspond with the average of a series of years' figures which is indeed an arithmetical abstraction and may possibly never occur." It would thus appear that there was considerable

vagueness even in the minds of the initiators as to the meaning of the term. Continuing to quote Shirras, " The Agricultural Department in each province maintains a statement of the normal or average yield per acre of land of average quality (under the two major heads of irrigated and unirrigated land) for the several crops in each district. In order to test the accuracy of these standards of normal or average yield and to revise them, if necessary, a system of crop cutting experiments is in force in all the provinces. Under this system plots of land of average quality are selected and the crops grown on them are cut and weighed in the presence of responsible officers of the District staff or of the Provincial Agricultural Department. These experiments have to be carried out every year in respect of all the principal crops and in accordance with rules specially framed by the several provincial authorities (though, apparently this is not always done). The results of the experiments are reported to the head of the provincial Agricultural Department, who, on a careful scrutiny of all the reports received by him, and after such further investigations as he may deem necessary, revises or verifies the standards previously adopted for the districts or the province. The revision is ordinarily made once in five years."

This somewhat arbitrary and empirical system has from time to time been subjected to various criticisms. Quoting Stuart's memorandum again : " Our figures of the normal yield per acre of the several crops are based on crop-cutting experiments. I do not think that any province has taken a mere arithmetical average of all the crop-cuttings available as their figure of a normal yield. There has been a certain amount of discretion exercised, and we may perhaps define the figures now adopted as the opinion of experts based on crop cuttings and local information. Every one will admit that our figures of normal yield will not bear a very critical examination. We have been working from the particular to the general ; we have expected to obtain from a comparatively few scattered crop-cuttings, or small plots, an accurate average of the yield per acre of very large areas. I maintain that no feasible increase of crop-cuttings in the future can improve on figures of normal yield per acre to any appreciable extent. To obtain each year a useful " random sample " of the yield of a province would require an altogether unmanageable number of careful crop-cuttings. We must seek other methods." Stuart then went on to say that an endeavour should be made to obtain independent information as to what the total yield of the crop of any particular year had been. For this purpose use should be made of figures of transport by rail, sea, or river ; figures of produce passing through mills, presses, etc. ; and estimates of local consumption ; this to be checked by enquiries as to total yield of particular limited areas (villages) in particular years. The committee, however, which at the time of this memorandum (1919) reported to the Board of Agriculture in India, said : " In regard to the normal yield per acre, on which, of

course, all forecasts of out-turn must be based, we are, on the whole, not in favour of the abandonment of crop-cutting experiments. We consider, however, that if the results of these experiments are to be of real value in checking the figures of yield, they should be much more numerous and should be carried out much more rapidly than is at present the case, and that the villages and particular fields in which they are carried out should be selected at random and not in accordance with any rigid system."

This committee accepted Stuart's view that an attempt should be made to ascertain the total actual yield of the crops in regard to which forecasts are issued by the collection and detailed study of the statistics of movement by rail or sea, of manufacture, or of any process, such as baling and of estimates of local consumption and carry over. . . . "When this is done the total yield divided by the acreage should represent the average yield per acre. The average yield on which the forecast for any particular year will be based, will be the average of the actual yield of the ten years immediately preceding it for which figures are available. . . . We consider it desirable that the use of the term normal should entirely disappear in this connection, and that the result obtained by the methods we have described should merely be called the average yield."

The old system has, however, gone on, and such attempts as have been made to improve it have apparently not been altogether successful. The *Quinquennial Report on the Average Yield per Acre of Principal Crops in India for the period ending* 1921–22 says: "On an examination of the return for the quinquennium ending 1911–12, it was recognised that the results of the experiments as conducted by the district revenue staff were generally unreliable. A change in the system was, therefore, considered necessary; and in 1915 the Government of India, with a view to improving the returns, issued instructions to employ as far as possible the expert officers of the provincial Agricultural Department for carrying out experiments on a well-ordered plan in each agricultural tract, and for the investigation of average crop out-turns in the various provinces. The new system was introduced in the quinquennium ending 1916–17 in some of the provinces, mainly as an experimental measure, as explained in the previous report. *It appears from the present reports that during the quinquennium under review the new system was not fully carried into effect in most of the provinces.*"

The Seasonal or Condition Figure.—In most parts of India the cultivators are in the habit of estimating crop out-turn in terms of annas. In some parts of India a 12-anna crop and in other parts a 16-anna crop is taken as the normal standard; so that when asked to report on the condition of a crop, the "*patwari*" will say it is a five-anna crop or a ten-anna crop as the case may be, making a mental comparison with his idea of a normal crop and giving a figure for the results. "In 1897," says Findlay Shirras (2), "a

question arose as to whether the anna notation or the American notation should be used in making crop estimates, and it was strongly urged upon the Government of India that as the cultivators and village officers entrusted with the duty of collecting data for crop reports were mostly accustomed to the Indian system, i.e., the anna notation, the adoption of any other system would tend to confuse the estimate. It was, therefore, laid down by the Government of India that it should be left to Local Governments and Administrations to adopt such scales of notation as might be suited to local conditions, the object being to secure that the returns should be in terms of a normal crop. To secure conformity with local usage it might even be necessary to use different scales in different parts of the same province. But since the anna standard thus adopted would not possess any fixed or uniform value, it was ruled that wherever the anna notation was used in the local returns, the standard on which it was based, that is the number of annas taken to represent a normal crop, should be stated.

"It was also laid down that in published forecasts the anna notation should not be used, the American notation being used in its stead, 100 being taken to represent a normal crop and the estimated out-turn being stated as a percentage of that crop, the conversion of the anna estimate into the percentage estimate being made either by the district officer or by the provincial authorities."

Had the use made of the anna estimate been to express it as a percentage of a 10 years' (or longer) average of similar estimates, as is done in America, this method of estimation might have been regarded as fairly satisfactory. But it is clear that this is not in general done.

In the memorandum referred to above, Stuart remarked : "All over India, I believe the *patwari* classifies the crops *at the time of harvest* on the scale of the anna notation. I do not know exactly what is done with this in other provinces ; but in Madras a weighted average of this classification is worked out for each crop, and for each district. On the strength of this, we, most absurdly, published year after year the statement that the yield of a particular crop was only about 57 per cent. of the normal, until I had the system changed in 1917. *A similar reform would appear to be needed in other provinces.* It is quite futile to try and alter the ways of the *patwari* or other reporting agency by juggling with the anna notation, or by endeavouring to define a normal crop. All over India the *patwari* has a very clear idea of what he means by an 8-anna crop. It is something considerably better than a 4-anna crop, but inferior to a 12-anna crop. His standard remains fairly constant from year to year. The information provided by the classification is of real value, and all that is necessary for the full use of it is :—

(1) To translate it into intelligible language before it is published.
(2) To correlate it with actual yields.

Stuart then went on to say that the total yield of the year under report shown in Season and Crop Reports, which should be termed "final" estimate" and not "actual" should be calculated by the following formula :—

$$\text{Total Yield} = \text{Area} \times \text{Average of } \frac{\text{Actual yield}}{\text{Area}} \times \frac{\text{Seasonal Factor}}{\text{Average Seasonal Factor.}}$$

and this was accepted by the committee mentioned above. But we have not been able to find that it has been universally adopted.

A more subtle bias probably enters into the condition figures owing to their connection with taxation. For instance in the Bombay Presidency where the village accountants' normal is a 12-anna crop, if the crop is less than a 6-anna crop the revenue is suspended for that year, while if it is less than a 4-anna crop it is cancelled. In case of the suspended revenue the proportion payable in the following year is dependent on the crop in the latter year. Thus the supervisor who revises the village accountant's estimate and who likes to have the reputation of being an efficient revenue officer will tend to raise doubtful cases up to the 4-anna or 6-anna level.

To sum up, the reader will probably come to the conclusion that granted the necessity of a subjective method of forecasting and estimation, the acreage figures in India are extremely good, while actual yields and condition figures leave room for considerable improvement.

(iv) These three examples must suffice as descriptions of methods at present in use. How far they may be supplemented or ultimately replaced by more objective methods based wholly or partly on the weather, is a question which belongs properly to the section which follows.

I.C.—SCIENTIFIC WORK ON THE RELATION BETWEEN WEATHER AND CROPS AND ON CROP FORECASTING FROM WEATHER.

(i) Cycles.—It has already been mentioned that there are two lines on which research has proceeded; firstly, attempts to determine a cycle, or regular sequence, of a definite number of years at the end of which similar meteorological and, as a presumable consequence, agricultural phenomena are reproduced; and, secondly, attempts to ascertain the effects of different types of weather during or shortly before the growing period of the crop.

As regards cycles,among the best known of the earlier writers in this connection may be mentioned W. Stanley Jevons (3), who investigated the relation between crops and sun-spots. Among more recent writers who have provided materials for prophecies are Sir Napier Shaw (4), Sir William Beveridge (5), and Prof. H. L. Moore (6), of Columbia University. There seems, however, little doubt that Hooker's view may be accepted that "the chief difficulty in applying the undoubtedly significant results that have been attained, to anticipate the probable course of events in the future, seems to lie in the bewildering number of cycles actually or apparently determined." It is the second line of approach which offers the greater hope of success.

This line of approach consists in comparing deviations of the crop from the average with deviations of various meteorological phenomena from the average at all periods of the year or, at least, at those periods which may be suspected of exercising a predominant influence on the yield. Early investigators were badly handicapped by want of sufficient data. Meteorological statistics were abundant, but quantitative estimates of yields of crops were, fifty years ago, sadly lacking; indeed they leave much to be desired to-day. We accordingly find that the first students possessed only rather vague and unreliable records that crops in particular years were good, bad, etc. Hence the earlier essays treat the subject by noting what weather precedes markedly good or bad crops.

(ii) Early Researches.—Such a method was followed by Gilbert and Lawes in their classic enquiry into the relation between winter rainfall and the yield of wheat in the following autumn (1880, ref. 7). They compared the deviations of rainfall and temperature from the average in fourteen selected seasons, historically abundant or the reverse. They concluded, *inter alia*, that seasons of highest productiveness were characterised by higher than average temperatures during most of the winter and early spring and a prevailing deficiency of rain in winter and spring. Meagre as was the material, Gilbert and Lawes studied it from the point of view of the trained scientist, and suggested the reasons, namely, the hindrance to root development presented by a saturated soil, and the washing out of nitrates by abnormally heavy rains.

Their paper may justly be regarded as the starting point in this country of scientific investigations into the subject.

When actual statistics of crops began to be available in sufficient quantity, the records of yields of a series of years were all utilised, being divided into two groups according as the yield was above or below the average yield. Deductions were then drawn from important differences found in the average of the meteorological phenomena in the corresponding years.

This method was, indeed, adopted several years before the work of Lawes and Gilbert was published, by Sir Rawson Rawson (1874, ref. 8), in examining the relationship between the sugar crop and rainfall in the island of Barbados. His data indicated that the important factor was the rainfall, not of the growing season, but of the preceding year, and he went on to establish the conclusion that every inch of rainfall (of the preceding year) eventuates in a yield of 800 hogsheads of sugar in the whole island (the area having been fairly constant for many years). The results of such a rough method of estimation were surprisingly good. The data were recently re-investigated by Leake(19) using a more refined method based on his idea of " effective rainfall."

The standard deviation of the percentage difference of calculated from actual yields over the years 1857–73 was 11·61 per cent. on Leake's formula and only 13·04 per cent. on Rawson's.

(iii) Researches in England.—No further advances were made until about 25 years later, when Sir Napier Shaw took up the problem. In a short note (9) read to the Royal Society on February 2, 1905, he pointed out that there was " a striking similarity " between the curves of autumn rainfall for the " Principal Wheat Producing Districts " and the yields of wheat per acre for the whole of England over the years 1884–1904, and suggested the following empirical relation :—

Yield = 39·5 bushels per acre — $\frac{5}{4}$ [the previous autumn rainfall in inches].

He found that while the extreme variation of the yield in the 21 years was 9 bushels, the yield computed from the equation agreed with the actual yield in 7 years within half a bushel, and in 14 years within 2 bushels, while in the remaining 7 years the difference between computed and actual yields exceeded 2 bushels. The worst discrepancy obtained was in 1886, when the actual yield exceeded the computed by 4·5 bushels.

In a paper read to the Royal Statistical Society (10) on 21st March, 1905, Shaw again referred to this subject and compared, for the Eastern Counties over the years 1885–1904, the deviations of the wheat yield from the average with the deviations from the average of the previous autumn's rain. He found that omitting 1888, 1889, 1890 and 1903 the yield goes down as the autumn rainfall goes up, or putting the matter in a different way, with the exception of the years 1889 and 1903, when the yield is above the

average the previous autumn rainfall is below the average and *vice-versa*. In a later paper (4) Shaw gave the empirical formula for Eastern England:

Yield in bushels per acre = 46 — 2·2 [rainfall of previous autumn in inches].

R. H. Hooker's investigations must now be mentioned. They have been described as a model of lucidity and cautious deduction, and have undoubtedly supplied the inspiration to many of those investigators who have since undertaken similar work. In fact his 1907 and 1922 papers taken together may justifiably be regarded as classic investigations of the problem by modern statistical methods.

In a paper read to the Royal Statistical Society in 1907 (11) Hooker gave the correlations, total and partial, with rainfall and accumulated temperature of each of the principal crops (wheat, barley, oats, beans, potatoes, turnips and swedes, mangolds, " seeds " hay and meadow hay), for Eastern England over the years 1885–1905. The correlations were calculated at overlapping intervals of eight weeks.

" One feature stands out," says Hooker, " with, to me, quite unexpected prominence, and that is the advantage of cool weather during spring and summer for the great majority of the crops. Indeed there is no coefficient, with the exception of those with potatoes, that even seems to suggest the possibility of warmth at that period being other than detrimental. What is to be noticed more particularly, however, is that it is not because cool weather usually accompanies a wet May and June : the calculations I have made practically eliminate the influence of the rain, and show that it is really with cool weather, irrespective of rain, that the relationship exists. If rain comes also, it is as a rule acceptable, and in the case of oats especially rain is required, more particularly somewhat earlier. . . . The different behaviour of the grass crop may be noticed. Consideration of the coefficients prior to April points to the desirability of weather conditions which do not allow it to make much progress before then (once the seeds have had a good start) and the greatest bulk seems to be secured when the grass can respond with sudden growth to the spring rains.

Root crops also appear to want cool weather throughout the summer—not rain : they want rain in the late spring and early summer only. In their case the evidence, although the different crops corroborate each other, is not so strong as with cereals ; still it seems probable that a good start, and cool weather to follow to allow of persistent uninterrupted growth are the optimum conditions."

Hooker's second paper (12), his presidential address to the Royal Meteorological Society in 1921, was principally concerned with a review of the scientific work on crop forecasting and the relation between weather and crops which had appeared up to that date. He reproduced, however, forecasts of the 1907 harvest, which he had made on the basis of the weather up to the end of August, 1907.

"My forecasts, prepared in a study in London, from the records of the weather up to the 36th week, proved quite reasonably close to the actual yields ascertained later in the autumn, in fact though a measured comparison is not easy, they were on the whole rather nearer than those published in September by the *Times*."

In his third paper (13), Hooker recalculated all the values of his 1907 paper on the data provided by the 37 years 1885–1921.

"It may be said at once that on the whole the figures found fifteen years ago are mostly somewhat toned down; the largest coefficients are often somewhat reduced; especially those with the preceding season, so that it may be inferred that the influence of quality of seed is not quite so marked as was indicated by the 21 years ending 1905. But apart from the conclusions being on the whole rather less categorical the results are similar."

It is no disparagement of the great pioneer work of Hooker to say that the method he adopted is somewhat difficult of interpretation, and that it is not ideally suited to form the basis of a forecast.

The correlation of yields with rainfall or temperature at eight-weekly overlapping intervals is at times difficult of interpretation, and it is scarcely possible to determine which periods (of rainfall or temperature) are directly correlated with the crop yields, and which correlations are due to the rainfall or temperature in different periods being correlated with each other.

If the results are used as a basis for forecasting it is necessary to select critical periods, where the correlation with yield is certainly significant, from which to calculate a forecasting formula or a regression equation as it is technically called; each critical period so selected provides a different formula, and it is necessary to combine the results obtained in some apparently reasonable but really partly arbitrary manner. Further it is never quite clear where we should draw the line between critical and non-critical periods.

These difficulties, which were duly recognised by Hooker, were met by a new method introduced by R. A. Fisher (14 and 15).

Fisher had at his disposal the yields of wheat on Broadbalk field at Rothamsted, on which wheat has been grown under experimental conditions continuously since 1844.

Thirteen plots at Rothamsted had been continuously under uniform treatment since 1852, the manurial treatment, of course, varying from plot to plot; thus Fisher had at his disposal a series of wheat yields on thirteen different plots over a period of 65 years. Further, the yields were derived from measured plots by actual weighing.

There were, in addition, rainfall data available over the years 1854–1918, derived from a large gauge (·001 acre) built for the purpose; thus there was a series of data of unique length for the purpose of a crop–weather study.

Fisher first studied the wheat data alone (14) and found :—

(i) That on many of the plots a progressive diminution in yield was observed owing to the exhaustion of the soil in certain of the essential plant nutrients.

(ii) On all the plots slow changes in yield had taken place which may probably be ascribed to variations in the weed infestation of the field as a whole ; this variation, unlike that ascribable to other causes, was in all the plots approximately proportional to the mean yield.

After allowing for these sources of variation Fisher not only found how much of the remaining variation was due to rainfall, but, by an extremely ingenious mathematical method he arrived at curves for each plot, giving the average effect in bushels per acre of one additional inch of rain at any time in the year. The additional inch of rain is measured from the average of the particular plot for the particular date considered (the existence of secular trend making the average vary from year to year) and the average effect in bushels per acre determined from the rainfall has then to be added to the average wheat yield for that particular plot and year to obtain the probable yield in a year of that specific rainfall.

The great advantage of the method for forecasting is that the rainfall up to any given time in the year, say June, provides an immediate and unique basis for a forecast at that time, the future rainfall being supposed to have its average values. Fisher found that on all the plots dry weather (i.e., weather with less rainfall than the average) was generally beneficial and that a detailed comparison of the plots indicated a predominant influence of the effect of rain in removing soil nitrates.

The main difference between Fisher's and Hooker's results is that, whereas Hooker found a dry previous autumn to be advantageous to the crop, Fisher found rainfall above the average either slightly beneficial or less harmful than at other times.

Fisher regards the discrepancy as due to the fact that under industrial farming conditions rain in late autumn and early winter prevents the sowing of large areas of wheat, the land being sown in spring with oats or barley. " This is a factor which must strongly influence Hooker's results, whereas under experimental farming conditions it is inoperative." Fisher also considers that the fact that Hooker's series appears to incline on the whole to more positive values than are observed in his own regressions is not improbably due to the inclusion in his data of yield from lighter lands, more susceptible to summer droughts than is the heavy loam of Broadbalk ; in addition Hooker's mean rainfall is some four inches less than in Fisher's series.

It would be of extreme interest to see the results of Fisher's method applied to the official estimates of yield for a few counties and for the whole country ; such a study would not only, in all probability, throw light on the problem of forecasting, but on the

question as to whether, as has been suggested by some critics, the official figures tend to minimise variations in yield both above and below the average.

This question has already been referred to in Section I B (i), p. 11.

(iv) Wallen in Sweden.—Among researches elsewhere in Europe that of Wallen in Sweden is outstanding (1917 and 1918, ref. 16 and 17). He calculated the correlation between rainfall and temperature on the one hand and the yields of four cereals (wheat, barley, oats and rye) on the other, for each of the 26 governments of Sweden in every month of the growing period during the thirty years 1881–1910. He duly allowed for the progressive raising of the standard of production, and he established regression equations and compared the theoretical yields calculated from these latter with the actual records of harvest in each year of the period examined. The closeness of fit of these last comparisons not only shows the value of the method, but also affords us an idea of the average error and what is equally important, the range of error to be expected from forecasts framed in this way.

Wallén has also drawn diagrammatic maps illustrating the correlation in each province of Sweden : provinces where the correlation between crops and particular meteorological phenomena is positive are coloured black and those where it is negative are coloured red. In quite a number of these maps the northern part of the country is of a different colour from the south, intermediate areas being colourless. This is to say that at particular times of the year a given crop in the south of Sweden prefers cool or dry weather, as the case may be, while in the north warmth or moisture is wanted, or *vice versa*. These maps are strong corroborative evidence that the central part of Sweden is in those cases nearer the optimum for the particular crops in that country.

Wallén's work represents one of the fullest developments hitherto made of the methods of research into the relation between the weather and the crops. His work, among other things, included the calculation of 2,880 correlation coefficients.

In formulating his conclusions Wallén divides Sweden into four districts : the first being the most southerly and the last the most northerly, the other two intermediate.

(1) In the most southerly districts he finds relatively low temperature in August (of the year of sowing), high in September and October, low in November and December, high in January, February, March and April, low in May, June, July and August to be more favourable for wheat. As regards rainfall he finds less than the average rainfall favourable in autumn as well as in spring and summer, except for the month of May, when abundant rainfall is favourable to wheat. The resemblance here to Hooker's and Fisher's conclusions may be noted.

(2) " In this (more northerly) group the favourable variations for wheat seem to be on the whole similar to those in the preceding group, except that summer temperature should be above the average. As for the rainfall, plentiful falls in August and September of the year of sowing and little rainfall in October and November seem to be the best, while in the spring and the summer rainfall does not seem to play a very important part.

(3) " In the third group the coefficients resemble those in the last group, but a temperature above the average is favourable during the whole of the growing period except in the first two months (August and September). The curve (or correlations), however, shows depressions in November and December, as well as in May and June corresponding to the negative values in these months in the previous groups. For rainfall the curve shows that plentiful falls are preferable in August and September (of the year of sowing) as well as in April or May, but that otherwise less rainfall than the average is the more favourable.

" The curves for rye are very much like those for wheat. In the first group the curves are almost identical. In the second group it appears that a low temperature in November and December is more necessary for rye than for wheat. The positive correlation of the winter months is also smaller for rye than for wheat. This difference appears even more markedly in the third group where the mean coefficient even for January is negative. These differences are naturally due to the different responses of the two cereals to frost. The advantage of a low temperature in August and September is very accentuated in this group. As regards the mean curves of correlation between rye and the rainfall there are no notable divergences from the curves already treated for wheat. However, it seems that high rainfall in summer is more dangerous for rye than for wheat.

(4) " The fourth group includes the governments situated farthest north. The curve shows a temperature higher than the average to be most favourable, except for the months of August and September. Depressions (in the curve of correlations) analogous to those in the preceding groups can, however, be observed in January and June. The curves for rainfall show that abundant falls are to be preferred, both in the autumn and spring months, and especially in June."

Wheat and rye are autumn sown crops in Sweden. Wallen also discusses spring sown crops, barley and oats. His regional groups, though slightly modified, are substantially the same.

" The first group gives for barley and oats practically identical curves for relationship with temperature. In March the correlations are positive, although very small, but subsequently it seems more favourable to have low temperatures. For rainfall the curve shows that abundant falls are on the average the most favourable in May and June, but unimportant in the following months.

" The second group shows that low temperatures are to be preferred for barley in July and for oats in June and July. As to

rainfall, abundant falls are very favourable in May, June and July but not in August.

"For the group farthest north warmth dominates, and the correlations with temperature are positive during the whole of the growing period. Abundant falls of rain are useful for barley in June only, and for oats in June and July."

The reader is recommended to refer to Wallén's paper itself for greater detail, and to see how remarkably thorough a study has been made.

(v) Researches in the Empire.—(Va) Among the more noteworthy researches on this subject in the Empire may be mentioned those of A. Walter in Mauritius (1910, ref. 18) and S. M. Jacob in India (1910, ref. 20 and 1916, ref. 21).

Walter, whose work, taking into consideration the time at which it was written, must be regarded as a most important pioneer research, has carried out an exhaustive analysis of the influence of the weather upon the sugar crop of Mauritius. He first finds equations between the yield of sugar per "arpent" (1·043 acres) and the "degree of wetness" at various periods of the year during 1892–1905 on three separate estates and computes the theoretical yield on this basis for each year. He then takes the residuals, i.e., differences between the crop thus computed and the actual yield, and finds the relation between these residuals and the temperature. In these calculations, the three years 1892, 1901 and 1902, when severe damage was caused by cyclones, are omitted; but, subsequently, computing the theoretical yields in these years from the wetness and temperature, he uses the difference between these and the actual yields as a basis for calculating the loss due to cyclones. He thus obtains a formula for evaluating the damage caused by a cyclone in terms of (1) the maximum pressure of the wind, (2) the length of time the velocity of the wind was over 40 miles per hour, (3) the epoch at which the cyclone occurred, and (4) the amount of angular change in the direction of the wind during the cyclone. Of course the number of years observed (14) was small, and the cyclone calculations rest upon the results of only 3 years.

An endeavour was made to put the results to commercial use as a basis of payment by underwriters to growers for the amount of sugar lost as the result of cyclonic damage, but the underwriters were shy, perhaps because of the paucity of the data available for estimating the effects of the cyclones.

Some explanation must be given of the term "degree of wetness" as defined by Walter. It is in the first place defined as $R\frac{t'}{t}$, where R is the total rainfall in the month, t the number of days in the month, and t' the number of rainy days. In other words it is considered that the same amount of rainfall has more effect if it is spread over the month than if it is concentrated on a few days.

But in addition to this Walter found five months in which the degree of wetness appeared to exceed the limit which the crop could utilise, viz., March, 1895, February, 1896 and 1902, and January and March, 1905. Walter says: "Before proceeding to a numerical determination of the relation between the rainfall and the crop it was necessary to eliminate, partially at least, the non-effective rainfall; and it was thought that if it were possible to determine the depth to which a given fall penetrated, the amount which passed beyond the limit of the cane roots might be rejected. A preliminary discussion of the temperature of the soil, as recorded by thermometers at depths of five feet and ten feet, respectively, below the surface, revealed the fact that certain heavy rainfall caused an increase of temperature at these depths. A detailed discussion of these observations is in course of preparation, and it is hoped that it will throw further light on the cause of this phenomenon, which is probably due to increased conductivity of the soil. In the meantime it has been considered that during excessively wet periods rainfall which increases the temperature at a depth of five feet raises the moisture content of the soil to such an extent that a further fall, in the excess of the evaporation from a free water surface, is non-effective, and has, therefore, been rejected.

"In determining the different contents, the data for the year 1896 have been omitted, as it was impossible to decide, on account of its exceptional intensity, what portion of the February rainfall should be rejected. In fact it is probable that rainfall of this description is positively harmful.

"The soil becomes saturated, the fertilizing matter is washed out, and in those places where the subsoil contains a large percentage of clay the soil remains water clogged for some considerable time."

The actual degree of wetness $\left(R\frac{t'}{t}\right)$ for February, 1896, was 19·67 in., for March, 1895, it was 20·95 in., for February, 1902, 13·14 in., for January, 1905, 21·15 in. and for March, 1905, 13·10 in. For the last four months Walter took as his "effective" degrees of wetness 11·95, 8·65, 15·06 and 10·00 in., respectively.

He does not give the details of this determination, and says that the method adopted is to a certain extent empirical, but in any case he was faced in this respect with a very difficult problem. Other workers in the tropics have emphasised a distinction between rainfall and "effective rainfall," notably Leake in a recent paper (1928, ref. 19).

Leake takes as his effective rainfall on any day—

$$E_n = r_n + kr_{n-1} + k^2 r_{n-2} + \ldots + k^{n-1} r_1$$

where r_n is the rainfall of the 24 hours ending 8 a.m. on day n, and k is determined empirically.

In addition to the calculations to which reference has already been made, Walter obtained by similar methods a prediction formula

for the total sugar crop of the whole Island. This was based on the years 1886–1907, and Walter succeeded in predicting the 1908 crop within 3 per cent., though in some of the previous years considerably larger residuals were obtained.

(Vb) Jacob's first paper is "On the Correlations of Areas of Matured Crop and the Rainfall, and certain allied Problems in Agriculture and Meteorology." (1910, ref. 20.)

He used crop and rainfall data from the Sialkot district, a rather limited area in the Punjab. In each of five "*tahsils*" or sub-districts 30 villages were chosen and the "areas of matured crops" over the years 1887–1906 in these villages were correlated with the rainfall. In the case of autumn harvested ("*Kharif*") crop the rainfall used was that of the six months April to September, inclusive, while for spring harvested ("*Rabi*") crops the rainfall of the six months October to March was used.

Regression equations were worked out, the correlations for the autumn harvest being from ·4 to ·5 and for the spring harvest from ·6 to ·8. In the case of two "*tahsils*," the spring harvests were also correlated with the rainfall from September to March, inclusive, and the autumn harvests with the rainfall from April to August, inclusive. A comparison of these with the former results revealed the fact that rain in September is beneficial both to the autumn and the spring crop, probably only slightly to the former and considerably to the latter.

Jacob considered the accuracy of the rainfall data to be satisfactory but the crop data to be more open to question. "In respect of the matured areas of crops the data are less satisfactory. In the Punjab these data are based on a rough estimate of the relative amount of the grain and straw bearing crop in each field examined by a local official, and compared mentally with what he believes to be a normal out-turn of crop. In many cases, too, it is feared that the estimate is made without seeing the field, merely from hearing and by a judgment of the probabilities of the case. The area of each field is quite accurately known, and it is only in this mental comparison of the produce of a unit area that serious errors arise. The "average" or "normal" is solely the estimating officials conception of what a "normal" harvest should be. Though, of course, persons of long experience will agree to some extent in their conception of the "normal" or "average" harvest, yet so far as I know, it has never been quantitatively defined. Whether the total yield should be measured by weight or by volume, what proportions of grain, chaff and straw it should contain, what percentage of moisture should be deducted and so forth are all questions which would have to be answered if an accurate standard is to be set up; and the need for some such standard appears to be very great.

Yet, in spite of indefiniteness in these respects a certain tradition as to what constitutes an average crop, made more precise by experiments on the yield of certain crops, exists, and as a unit of measure-

ment is not quite the inadequate instrument that it might appear to be at first sight.

When the ratio of the actual yield to the assumed average has been determined to be, for instance, three quarters, then a field of an area of 1 acre of this kind of crop is entered in the Government papers as three-quarters of an acre of matured crop. It is the areas of the crops so estimated which form the closest measure of the real out-turn at present obtainable, with which we are here concerned."

In view of the discussion of this subject already given (I B iii), not much further need be said on it here, but the difficulties of prediction from inadequate data cannot be over-emphasised nor the need for a sufficient number of adequate field experiments, the produce of which should be weighed. In some provinces no doubt the crop-cutting experiments in existence would form the nucleus round which such a system of experimentation might grow.

Jacob concluded his paper with the discussion of rainfall variation from year to year in which he attempted the use both of Pearsonian frequency curves and periodic curves. For the time at which it was written, this work, which was performed without knowledge of Hooker's, was an important advance.

In Jacob's first paper only the general effect of the whole summer and winter rainfalls on the autumn and spring harvests, respectively, was considered. In a second paper (1916, ref. 21) the effect of varying distributions of rainfall was specifically dealt with and the more important crops were treated separately. The area considered was the Jullundur *tahsil* of the Jullundur district of the Punjab, an area of 428 square miles, of which about 390 were cultivated. Three assessment circles were considered over the years 1885–1914.

As regards acreage the areas of—

(1) Well irrigated wheat,
(2) Unirrigated mixed wheat and gram,
(3) All unirrigated crops for the spring harvest,

were correlated with the rainfall in July, August and September. The correlations found were somewhat low, the true correlations being masked by negative correlations between the rainfalls of the three months considered.

For this reason the multiple regression equations between the area of well-irrigated wheat sown in one of the circles and the rainfall in each of these three months were calculated, both with and without making allowance for the number of wells introduced. The latter formula gave a prediction with a probable error of only 5·6 per cent. of the mean.

It was not found possible to treat individual unirrigated crops separately :—" The prediction of the sown areas of individual unirrigated crops," says Jacob, " is very desirable, but except for the principal crop, wheat and gram combined, the problem will

require a finer analysis than by the total rainfall of the month. Thus, the 30th of September is a critical time. If sowing conditions are favourable before that date a great deal of gram is likely to be sown, but if suitable rain falls after that, gram is almost always combined with wheat." Accordingly, the sown areas of all unirrigated spring crops together were correlated with the August, September and October rainfall, and a prediction formula was obtained, the probable error being 9 per cent. of the mean. Jacob's forecasts of acreage were decidedly more accurate than the official forecasts.

As the basis of his prediction of *out-turn* Jacob used the so-called "*Kharaba*," which is merely the *patwari's* estimate of the deficiency of the particular field below what he considers a normal value. This estimate, open to several objections already discussed, was the best obtainable. Correlations were calculated between these estimates for a variety of crops and the rainfall in September, December, January, February and March, but only the unirrigated wheat in one circle was considered in detail. On the basis of the fifteen years 1901–15 a provisional regression formula was calculated, based, as Jacob recognises, " on the erroneous assumption that the rainfalls in these five months are not correlated with each other."

More stress is here laid by Jacob on a method adapted from one used by J. B. Kincer in dealing with Texas cotton, in which the rainfall in each month is weighted empirically, according as it is above or below the normal for that month, and according to the sequence of months above or below the normal. The weighted rainfall in each month was added together and a coefficient of benefit " B " was obtained, and this was correlated with the area of unirrigated wheat for 1900–15. A correlation of —·91 was obtained with the estimates of deficiency. Kincer's method will be considered below (p. 41); it may however be mentioned here that caution must be exercised in judging of the significance of a correlation between yield and an empirically constructed variate, as it is not quite easy to get a measure of the constraints introduced or, as we might say, the degrees of freedom absorbed, by the empirical method of constructing the variate.

(vi) Researches in the United States.—Many contributions to the study of the relation between weather and crops have been made in the United States, and, although no doubt some of the work is somewhat superficial and ephemeral in character, being based upon insufficient data, and treated by unsatisfactory methods of analysis, yet, on the other hand, much valuable work has been done.

First of all, mention must be made of H. L. Moore's study (1917, ref. 22). It is important because it was perhaps the first scientific criticism to be made of the official method of forecasting (described in Section I B ii). Moore drew attention to the close relationship between U.S. crop yields and rainfall, and in 1917 published an

important piece of research into the possibility of forecasting yields and prices of the U.S. cotton crop by correlational methods.

Among the conclusions at which Moore arrived the following may be listed :—

1. When the official U.S. cotton forecasts are subjected to critical examination the chief facts discovered are these :—
   (*a*) The official *May* report has no value whatever as a basis on which to forecast the average yield per acre of cotton.
   (*b*) The official *June* report has a measurable, but small value as a basis of forecasting the ultimate average yield per acre.
   (*c*) The official *July, August and September* reports have a decided value as bases of forecasting the average yield per acre.
   (*d*) The method of the U.S. Bureau of Statistics has inherent defects that tend to an under-estimate of the yield and thereby favours the producers.

2. When forecasts of the yield of cotton in four representative States, Texas, Georgia, Alabama and South Carolina, which in 1914 produced 65 per cent. of the total U.S. cotton crop, were prepared on the basis of rainfall and temperature statistics alone, it was discovered that :—
   (*a*) In 17 out of 20 cases the yield forecast from the weather statistics was more accurate than that forecasted by the official methods.
   (*b*) For all four States the forecasts by the official method from the *May* report were worse than useless. On the contrary the forecasts from the May weather had a real value. The forecasts from the weather for Georgia and South Carolina were, at the end of May, better than the official forecasts for June and nearly as good as the official forecasts at the end of July ; and the forecast from the weather for Alabama at the end of May was nearly as good as the official forecast at the end of September.
   (*c*) For three of the four States the official forecasts from the *June* report were worse than useless. But the June forecasts from the weather were in all cases of decided value, being in all three cases better than the official forecasts for July.

3. For all of the States, except Texas, the forecasts from the weather give, for each month, a more accurate prediction than can be obtained by the official method one month later.

4. For all of the States, except Texas, the forecasts from the weather give, for May, June and July about as good predictions as can be obtained by the official method *two months* later.

Moore also showed that it was possible to forecast the cotton acreage, several months before the crop was planted, with a degree of precision as great as the official forecast of yield made after the crop had completed its growth and was about to be harvested. His forecasts of acreage depended upon the total production and price of cotton in the previous season.

It may perhaps be of interest to describe briefly the method by which Moore arrived at his conclusions. He used the yield per acre of cotton in the U.S. over the years 1890-1914. Now, Moore pointed out that if C be the condition figure of the cotton crop in any month of any year, $\bar{C}_5$ the corresponding mean condition figure of the last five years; and if Y be the actual yield per acre in any year, $\bar{Y}_5$ the mean yield in the last five years; the official method of forecasting consisted essentially in equating $\frac{C}{\bar{C}_5}$ and $\frac{Y}{\bar{Y}_5}$ in order to determine a forecast for Y. Now, writing

$$\frac{Y}{\bar{Y}_5} = y \text{ and } \frac{C}{\bar{C}_5} = x$$

the regression equation of y on x is $y - \bar{y} = \frac{r\sigma_y}{\sigma_x}(x - \bar{x})$

The official method was thus assuming linear regression, $\frac{r\sigma_y}{\sigma_x}$ to be unity, and y equal to x. Moore showed that the first two assumptions were not far from the truth in the later forecasts, but that a quite unnecessary bias was, in the data he examined, introduced by assuming $y = x$ the former being in fact the greater As his estimate of the accuracy of the official forecast Moore took

$$S' = \sqrt{\frac{1}{N}\Sigma\left(\frac{Y}{\bar{Y}_5} - \frac{C}{\bar{C}_5}\right)^2}$$

N being the number of years used. He was thus able to compare the accuracy of the official forecast, both with the accuracy of correlating $\frac{C}{\bar{C}_5}$ and $\frac{Y}{\bar{Y}_5}$ and of his regression equation on rainfall and temperature. The following figures he gives are of interest :—

TABLE XIV.

Accuracy of U.S. Official Forecasts.

Correlation between $\frac{C}{\bar{C}_5}$ (x) and $\frac{Y}{\bar{Y}_5}$ (y) for the U.S. Cotton crop (1890–1914.)

Month.	r	$\frac{r\sigma_y}{\sigma_x}$	$S=\sigma_y\sqrt{1-r^2}$	$S'=\sqrt{\frac{1}{N}\Sigma\left(\frac{Y}{\bar{Y}_5}-\frac{C}{\bar{C}_5}\right)^2}$
May ..	—·049	—·105	13·79	16·05
June ..	·292	·655	13·20	13·61
July ..	·595	1·145	11·09	11·51
Aug. ..	·576	·866	11·28	11·74
Sept. ..	·685	·994	10·06	10·47

σ_x 6·45 σ_y 13·80

No immediate use appears to have been made of Prof. Moore's discoveries and method. In 1927, however, Bradford Smith (1927 ref. 23) published the results of an investigation into forecasting the volume and value of the U.S. cotton crop. In this paper he put forward methods for forecasting, *inter alia*, (1) the acreage of the cotton crop with surprising accuracy before the crop is planted, and (2) the probable yield per acre of cotton, based upon previous winter temperature in the cotton belt, this also being calculated before the crop is even planted.

The data used by Bradford Smith were somewhat different from those of Moore. They are, accordingly, of value in corroborating Moore's discovery that with the use of suitable data forecasts of acreage and yield of cotton in the U.S. of a pretty reliable kind can be made before the crop is even planted, and many months before U.S. official forecasts are able to attain any great degree of reliability.

A word of warning should, however, be given here against the somewhat spurious appearance of accuracy given by multiple correlation (or allied methods) between a number of variates in a short series. For example if one variate is predicted from (say) five others by the method of multiple correlation, the method itself introduces a certain measure of agreement between the observed and calculated values; in fact if we have but 13 values of each variate, as in one of Bradford Smith's prediction formulae, as a basis, a multiple correlation coefficient of ·86 will on the average, arise once in 20 times and one of ·92 once in 100 times purely by chance when there is really no underlying relationship between the variates at all. Thus, an artificial agreement is introduced between actual and calculated values over the period of the data; extrapolation for a year or two from the same formula would soon indicate its weakness, but this is a test which some inventors of forecasting formulæ are apt not to make, or if they do and the result is unsatisfactory, the essential conditions are said to have changed.

Bradford Smith's correlations are over ·9, and so almost certainly significant, but the association is not so close as such a high coefficient might lead the unreflective to believe.

Reference must also be made to the work of J. B. Kincer. In a paper on " The Correlation of Weather and Condition and Production of Cotton in Texas " (1915, ref. 24), Kincer gave a formula based on the hypothesis that the average temperature and rainfall conditions in Texas are the optimum for cotton and that departures either in excess or defect reduce the yield. Kincer's equation is given by—

$$X = d - \Sigma \left(\frac{ac + bc_1}{n} \right)$$

where X is the yield of cotton in pounds per acre, a the departure of rainfall from the normal, b the departure of temperature from the normal in any month, n the number of months used ; c and c_1 are empirical weights arbitrarily fixed, but were said to be assigned after a careful study of weather conditions for the period named in conjunction with the resulting yield for the respective years, and from a general knowledge of the effect on plant development of certain combinations of weather.

The rainfall weights depend on whether (1) a month of plus departure follows a month of like departure ; (2) a month of plus departure follows a minus departure ; (3) a month of minus departure follows a like sign ; (4) a month of minus departure follows the opposite sign.

The temperature weights depend on whether (1) a plus temperature departure occurs with a plus rainfall departure ; (2) plus temperature departure with minus rainfall departure ; (3) minus temperature departure with minus rainfall departure ; (4) minus temperature with plus rainfall departure.

For Texas Kincer found that d could be given the value 100, and gives a table of the empirical values of the c's. Such a table would naturally apply only to Texas. Over the years 1897–1913, Kincer obtained a correlation of ·88 between the calculated and observed values.

The objection to the method lies in the very great difficulty of interpreting such a correlation coefficient. If the rainfall be represented by a polynomial we can make a due allowance for the reduction of degrees of freedom caused by the number of constants in the regression equation, whose values have been obtained from the data, and so obtain a measure of the significance of the fit of the regression equation by using the known frequency distribution of the multiple correlation coefficient. But how many degrees of freedom are absorbed in the *empirical* construction of a variate, which is made to correlate as highly as possible with the yield data is a question which no one can answer. The position is rather similar to that which arises when a series of points is plotted, and the " best "

curve is fitted to them by eye. Any significance test under such circumstances probably tests nothing more than the ingenuity of the draughtsman.

Kincer has also made an interesting study of the relation of weather to the amount of cotton ginned during certain periods (1917, ref. 25). His data consisted of the ginning reports and temperature records of North and South Carolina, Georgia, Alabama, Mississippi, Texas, Oklahoma and Arkansas. The amount of cotton ginned up to a certain date (October 18th in Oklahoma and Arkansas, September 25th in the other States) was compared with the temperature of certain months (May and June for N. and S. Carolina, Georgia and Alabama, May, June, July for Mississipi and Texas, May, June July and August for Oklahoma and Arkansas) over the years 1905–15. The method consisted in comparing the departure of the number of bales from the average in each year with the departure of the mean temperature from the normal (or average) over the period considered in the same year. When plotted graphically the curves exhibited a striking similarity. The number of fair days in the period was also taken into consideration. Kincer concluded that a forecast of the size of the cotton crop, based on the ginning reports, has a much greater value when consideration is given to the influencing weather report factors than when the ginning report alone is considered. "For example, if temperature during the critical months be high and thus conduce to a rapid advancement and early maturity of the crop, and in addition the weather be favourable for picking during the period covered by a given early ginning report, say September 1st to September 25th, it may be safely considered that the percentage of the total crop ginned during the period will be much in excess of the average and the final yield less than that indicated by the actual amount ginned to that date. If, however, these modifying weather influences work in opposition and thus largely neutralise each other, then the amount ginned, whether above or below the average, gives a better indication as to whether the final yield will also show values above or below the average than in the other case. Furthermore, if the temperature conditions are unfavourable for early maturity and the percentage of fair days during the ginning period small, it may be safely assumed that the final yield will be larger than apparently indicated by the actual amount ginned."

"In studying the early ginning reports in connection with the two modifying weather factors under discussion, it must be borne in mind that the temperature has the dominating influence and should be given greater weight, but later, say for the period from September 25th to October 18th, the amount of fair weather during the period itself takes precedence.

"The fact that favourable temperatures during the early growing season are also conducive to comparatively large yields as well as to the early maturity of the crop should likewise be considered, and

it might also be noted that early maturity, in effect, postpones the date of first killing frost in Fall, by an equal number of days represented by the earliness of the crop and so diminishes damage from this source."

Finally reference must be made to a paper by Kincer and Mattice (1928, ref. 26) on "Statistical Correlation of Weather Influence on Crop Yields." The data here dealt with refer to North Dakota and Ohio over the years 1900–25. Fifteen different meteorological variates were available in the first case, 24 in the second, relating to temperatures, sunshine, rainfall, cloudiness or humidity at certain times. The essence of the method consists in picking out those variates which are most highly correlated with the crop-yields (spring wheat in North Dakota, corn in Ohio), and using these to predict from. Thus, in the case of North Dakota, each of the fifteen variates was correlated separately with the wheat yields. Sunshine in July (a) had the highest correlation with the yield (x). The multiple (double) correlations of x with a and each of the other variates were then calculated, that of x on a and e (total rainfall April to June, inclusive) turning out the greatest (·80). The yields were then computed from the regression equation of x on a and e, and the result was designated a new "weather index." a_1. The coefficients of double correlation of x with a_1 and all the other variates (except a and e) were then calculated, and the highest, that of a_1 and f (mean temperature June) picked out. From the resulting regression equation a new "weather index," a_2 was obtained, and the process repeated again, d (the mean temperature for July) being the variate to be combined with a_2, and m (the percentage of possible sunshine for June) with a_3. The final regression equation used for prediction was that of x on a, e, f, d, and m, a multiple correlation coefficient of 0·89 being obtained.

The objection to the method is that the process of selecting the most highly correlated variates vitiates any test of significance that could be applied to the value of the multiple correlation coefficient obtained.

With 25 years' observations and five *unselected independent* variates a multiple correlation coefficient of ·65 would occur once in twenty times and one of ·72 once in a hundred times entirely by chance when there was no real association between the variates at all, and even bigger values than these might occur by chance when we use a process of selection. The dangers of thus applying multiple correlation methods to small or smallish samples have already been pointed out by Fisher (1923, ref. 15).

(vii) This must conclude the review of scientific studies on crop forecasting throughout the world. An attempt has been made to pick out the most interesting and relevant, but doubtless, were there space, many more could be cited, particularly in America. Very many valuable references are given in Warren Smith's textbook on Agricultural Meteorology (1920, ref. 27).

II. VALUE OF CROP FORECASTS.

A.—INDIRECT VALUE OF CROP FORECASTS BASED ON WEATHER.

Considerable evidence has been adduced in the previous sections to show that forecasts of crop acreage and crop yields can be made on the basis of weather which, where adequate data exist, are more accurate than the subjective methods used in the official forecasts of most countries. This must not be interpreted as unqualified advocacy of the view that forecasts could not in some cases be further improved by taking into consideration not only weather but other factors as well.

In this connection physico-chemical factors such as soil, manuring and cultural operations may be enumerated, the previous cropping may be important, and economic factors such as price must not be overlooked. It is one of the advantages of the technique devised by Fisher, that it enables one to say *how much* of the variance of a given set of crop yields is due to one or more weather factors and so to consider whether it is worth while eliminating the weather factors and correlating the residuals with such other factors as may be susceptible of measurement. Thus scientific forecasting formulæ have, *inter alia*, an indirect value of considerable importance in assessing the influence of one set—perhaps the most important—of factors and, by eliminating their effect, leaving the ground clear for determining the influence of the remainder. Not much work has been done on the construction of forecasting formulae, which do in fact take other factors as well as weather into consideration. Such a procedure would raise problems the solution of which may well become possible when such data as are being collected under the British Agricultural Meteorological Scheme—assuming methods of collection adequate to ensure precision and comparability—have been collected over a sufficiently long term of years. Meanwhile, as has been seen, provided final estimates are reasonably trustworthy—and this is a point which must not be overlooked—the weather provides as good a basis for forecasting as any at present existing.

A knowledge of the normal effects upon yields of seasonal influences would also be of the first importance in all other scientific studies connected with crop yields. For only such knowledge can enable allowance to be made for the major influences of weather in comparison between crops grown in different years. In such a relatively simple question, for example,as to whether an agricultural area brought under cultivation or under irrigation in recent times was showing signs of deterioration, the direct examination of the trend of yields would be given a much greater precision and the signs of mischief brought to light many years earlier if the major seasonal fluctuations could be eliminated.

B.—DIRECT VALUE—CROP INSURANCE.

Were there data for all the principal crops in, say, twenty or thirty different places in Great Britain comparable with the Broadbalk wheat data at Rothamsted in the length of time over which they extend and in accuracy (the produce of each plot having been weighed), the working out of a crop-insurance scheme on the basis of the weather might well become a possibility. Indeed, Fisher has indicated how this might be done. Fisher's study on the effect of rainfall on wheat at Rothamsted provides data by means of which one may obtain the average yield in any year which may be anticipated on the basis of that year's rainfall. Calling this the expected yield, since 65 years' rainfall are available, 65 expected yields could be calculated, and from these we could calculate the probability of an expected yield occurring between given limits. The farmer would pay a given sum of money per acre of each crop insured in each year and, if the expected yield calculated on the basis of the year's rainfall fell, say, more than 10 per cent. below the general average of that crop, payments would be made to him of an amount per acre which would increase with the amount that the expected yield fell below the general average. And since the probability of an expected yield occurring between given limits is known, it becomes a simple calculation to work out how much should equitably be paid out to the farmer in the above-mentioned contingencies for each £1 per acre he pays in insurance.

But since the effect of rainfall on any crop would vary from district to district it would be essential to have data of this kind for as many districts as possible. It may be noted that under such a scheme any damage due to bad farming or neglect would automatically fall on the farmer and not on the authority undertaking the insurance, since the yield of his crop in such circumstances would probably turn out to be lower than the expected value for that year on the basis of the rainfall. The farmer has the same inducement as he has without insurance to make the best of a bad season. He is insured against unfavourable weather, not against a bad crop as such. No doubt much conservatism would have to be overcome before such a scheme were introduced, but it shows one use to which precise and comparable data, such as it is proposed to collect under the British Agricultural Meteorological Scheme, might be put.

C.—VALUE TO TRADE AND ADMINISTRATION.

The case for the value of accurate crop forecasts to trade in the United States has been well put by Olmsted (1911, ref. 28). Of their value to farmers he says :—" It is well known that speculators and large dealers in farm products do not depend entirely upon Government reports for information concerning crop conditions.

They have travelling agents and correspondents (usually local buyers) throughout the United States, who keep them posted; and the large buyer or speculator, in return, gives to those local buyers or correspondents information in regard to general conditions. These buyers know the condition of crops in their vicinity better as a rule than the average farmer, because it is their business to keep well informed. The farmer cannot, by refusing to report for his locality the condition of crops, prevent buyers or speculators from knowing the condition of the crop. But how about the farmer, if Government crop reports, which are largely by and for him, should be discontinued? He may know very well the condition of crops in his own locality, but he must depend upon reports of others, in the newspapers or otherwise,for the condition of the entire crop. Prices in his local market are influenced, as a rule, more by the condition of the whole crop than by local conditions. The entire wheat crop of his county may be destroyed and prices be low, if the entire crop is large; or his county may have a bumper crop and prices be very high, if the entire crop be short.

"Some private crop reports published in newspapers are honestly prepared and more or less reliable; on the other hand, misleading crop reports are frequently sent throughout the country to affect prices in the interest of speculators. Does the average farmer know which reports are reliable and which sent out to mislead? The Government reports are intended to enable farmers to keep themselves informed as to the general conditions. The question, then, resolves itself to this: Does it benefit the farmer to keep posted?

"But even those farmers who do not keep posted are indirectly benefited by the publication of Government crop reports, for these reports check and lessen the injurious effects of false reports sent out in the interest of speculators.

"The more certainty there is as to the supply and demand for a crop the less hazard or speculation there is in the business of distributing the crop, to the benefit, in the long run, of both producer and consumer.

"Large manufacturing firms, agricultural implement or hardware companies, who neither buy nor sell farm products, are much interested in the prospects and conditions of crops. This knowledge enables them to distribute more economically their wares, sending much to sections where crops are good and farmers have the power to buy, and less to sections of crop shortage, and therefore with less buying power. Few farmers realise how much is saved by the even distribution of wares which they buy which is secured from a knowledge of crop prospects. In this saving farmers in the long run are benefited.

"It is important to railroads to know the probable size of crops in the country in order to provide sufficient cars to ship the grain. The more nearly they can learn the size of the crops the better able are they to move them economically. Here, again, in the long

run, farmers are indirectly benefited by the cheapest distribution of the crop, due to better information of crop conditions."

Olmsted then goes on to show how knowledge in advance of the prospects of a basic industry, such as is agriculture in the United States, must mean a knowledge in advance of the demand for manufactured goods in large areas.

"Now, all classes of traders are obliged to act in advance. Retailers give their orders to wholesale dealers, jobbers or manufacturers many weeks, sometimes months, before actual purchase or shipment. Jobbers do the same, and so manufacturers are obliged to make their arrangements for the production of goods far ahead of their distribution and consumption. Thus any information which, even if only in part, enables the manufacturer to gauge the demand for his goods will tend to stop misdirected production and eliminate surpluses which could only be sold at a loss. . . . If reports show, during the growing season, that the condition of wheat is such as to indicate a full crop on a large area, the merchants of the wheat producing sections of the country know that they can give liberal orders for goods to be handled by them several weeks or months later; the manufacturers, located far from the wheat fields, know there will be a large demand for such of their products as are used by all dependent upon the wheat industry; the railroad companies know they will have heavy freights to transport, and so the advance knowledge regarding the probable future outcome of the crop serves as a guide to every branch of commerce and trade connected with the wheat-growing areas of the country. The same is true as to the other crops—corn, cotton, oats, rye, tobacco, etc.

"If, on the other hand, the condition of growing crops is unfavourable, reliable information to that effect is equally, in fact more, important to trade and commerce than when the promise is good. For when conditions are unfavourable, the merchants, manufacturers and transporters must move with a degree of caution not necessary when the prospects are highly encouraging."

Most of these conditions would hold equally in many parts of the British Empire, though doubtless they apply with greater force to the more developed areas. The advantages of crop forecasts above mentioned to farmers and growers would hold in the Dominions, and, indeed, in all parts of the Empire where there are white or other farmers and growers capable of understanding them.

Doubtless in India and elsewhere there are many native cultivators who would be incapable of so doing, but in such a case the information would be invaluable to the administration in looking after their interests. For instance, if reliable forecasts of famine were available in India the information would enable arrangements for transportation of food from one area to another to be made well in advance. There must be many other instances in the less-developed parts of the Empire where reliable crop forecasts would help the administration to further the interests of the people.

In Canada, Australia and in India, indeed in all parts of the Empire where there are manufacturers, the latter must be benefited by knowledge in advance of the agricultural demands for their products; nor does the advantage to railways in any extensive country of knowing in advance the probable demands on their carrying resources need emphasising.

Again, the state of the crops in one part of the Empire may be of interest in another; for example, if there were likely to be a shortage of food in Ceylon, compelling the Ceylon Government to import food, the information beforehand of such a contingency might be of great interest to the rice growers in Burma. In such a case, too, accurate forecasts of the Burmese crops would be of great value to the Burma administration in deciding whether there would be an exportable surplus.

Finally, reference may be made to the importance of accurate crop forecasts to the administration of a country in which the crops are important sources of the national income. This is particularly the case in India, where the taxation is based upon the crops, and also applies to those West Indian Islands in which a tax on the export of agricultural produce is an important source of revenue.

III.—THE FUTURE—IMPROVEMENT OF DATA.

A.—GREAT BRITAIN.

In an article in the Journal of the Ministry of Agriculture in July, 1926 (ref. 29), Mr. W. R. Black referred to the possibility in the future of estimating crop yields from meteorological data, and mentioned the steps taken abroad in recent years to study agricultural meteorology. He said that "except for isolated pieces of research on, for instance, the correlation between the weather and the yield of wheat by such investigators as Mr. R. H. Hooker and Sir Napier Shaw, and work by Dr. R. A. Fisher on the effect of weather on the yield of the experimental plots at Rothamsted, no serious attention was given in this country to agricultural meteorology until 1922," when a committee appointed by the Agricultural Research Council recommended that studies of three types should be encouraged :—

(1) General studies of the correlation between the weather and the crops in a particular area, by examination of the official data relating to crop yields and meteorological conditions in that area, with the object of increasing the accuracy of crop estimates.

(2) The organisation by the Ministry of Agriculture on a uniform plan of the collection of observations on the state of the crops (autumn and spring sown cereals, root crops, potatoes, grass and horticultural crops) and the incidence of insects and fungi, accompanied by meteorological observations of agricultural experiment stations in all parts of the country.

(3) The carrying out of special intensive studies of the reaction of crops to weather.

A scheme was drawn up to prosecute the second of the above studies, and was actually started in 1924. The data so far collected are at present under review with the object of estimating their value and of securing precision and comparability in the future. While meteorological data are adequate, it seems likely that very considerable improvements will have to be made in the crop observations. The scheme should ultimately provide data for such studies as are contemplated in (3). No official steps have been taken in relation to the first or third studies, for it was felt by the Ministry of Agriculture at the time that they were investigations which should be left to the research of an individual, and that they did not require official stimulus or co-ordination by the Committee.

It is, of course, open to any research institution to initiate such studies and a considerable amount of work has from time to time been undertaken, as by Tippett (53) on the effect of sunshine, by Hoblyn (65) on the analysis of temperature records, and in other unpublished work from Rothamsted. So far, however, no general

programme has been adopted concerning correlation between the weather and the official crop estimates in particular areas with the object of increasing the accuracy of crop estimates.

At the British Agricultural Meteorological Conference of 1926 Sir Napier Shaw referred to his own investigations of the effect of autumn rainfall on wheat and to those of Mr. R. H. Hooker as far as the Eastern counties were concerned, and said that similar material to that with which Mr. Hooker worked was available for other areas, and that further studies of this kind should be made. Dr. R. A. Fisher, of Rothamsted,had published a study of the effect of rainfall on the wheat yield of the Rothamsted experimental plots, and the results differed in some respects from those of Mr. Hooker, but they were for one place only. Dr. Gregory said that Mr. Hooker had worked on estimated yields only; there was doubt as to the accuracy of the latter, and this was probably the reason why Mr. Hooker's study had not been followed up. Mr. Eden pointed out that it would be difficult to apply the method of Dr. Fisher to fields or plots at crop weather stations grown under rotation unless a considerable number of years' work at the same station was available. The British Agricultural Meteorological Scheme is described in Mr. Black's article (1916, ref. 29).* Perhaps the primary aim of the scheme may be said to provide abundant and accurate materials for the science of plant physiology, but that the relation between weather and final crop yields must naturally be studied in the course of the investigation is obvious; this study will form one of the many studies to which the materials collected will give rise, and hence the need for accurate and uniform weighings in the data collected under the scheme. It is, of course, realised by the British Agricultural Meteorological Committee that their scheme will require records extending over many years before the records can be regarded as adequate for final statistical analysis.

Meanwhile the official figures might well be examined with the object of improving crop forecasts; such a research would be most valuable and ought to be considered in relation to the data of the Agricultural Meteorological Scheme. As a first step Fisher's method might be applied to the official estimates in a particular area. If the regressions turned out uniformly smaller than in the case of the Broadbalk data, this would lend weight to the view, already considered above, that the official estimates are too near the average both in good and bad years. Ultimately the analysis of the official estimates might be compared with the analysis of weighed yields from experimental plots in places other than Rothamsted, but some years must elapse before such data are available. There is no reason why, given sufficient clerical assistance, the Statistical Department at Rothamsted should not undertake an examination of the

* *See also* paper for the present Conference on Agricultural Meteorological Work in Great Britain.

official estimates. This department is already examining the statistical aspect of the Agricultural Meteorological Scheme, and such a course would ensure an examination being made in the light of all the associated data available.

Such a research into the relation of the official estimates of yield with rainfall and temperature since 1885 should deal separately with suitable districts (groups of counties) covering the whole of the country. It is suggested that 12 or 15 or even more districts should be dealt with, smaller in area than the large area "England, East," chosen by Hooker. Advantage would be taken of the improvements in methods of statistical analysis that have taken place since Hooker's work was published. There is probably no other piece of mainly statistical research that could be undertaken on behalf of the Ministry of Agriculture and Fisheries that would lead to results more likely to be fruitful in connection with the regular work of the Statistical Branch; it should also form an important contribution to the science of Agricultural Meteorology.

B.—THE EMPIRE.

In Great Britain, while crop data are capable of very considerable improvement, meteorological data are, on the whole, adequate. In the Empire, on the other hand, it is probable that in some places meteorological data are also capable of improvement.

Improvement might take the form of:—

(1) Better equipment.

(2) A greater number of stations.

The question of equipment is so bound up with conditions in particular areas that no general discussion of the subject seems possible here. For example self-recording instruments are desirable if there is some one on the spot capable of keeping them in order, but not otherwise. It is hoped that delegates will give the Conference the benefit of their experience on this subject as regards the parts of the Empire with which they are familiar.

In general it may be said to be desirable that where there is an important crop-weather research station, the meteorological data collected should be such as to rank the station as one of the First or at least the Second Order of the International Classification which is as follows:—

(1) *Normal Meteorological Observatories* at which continuous records or hourly readings of pressure, temperatures, wind, sunshine and rain, with eye observations at fixed hours of the amount, form and motion of clouds and notes on the weather are taken.

(2) *Normal Climatological Stations* at which are recorded daily, at two fixed hours at least, observations of pressure, temperature (dry and wet bulb), wind, clouds and weather,

with the daily maxima and minima of temperature, the daily rainfall and remarks on the weather. At some stations the duration of bright sunshine is also registered.

(3) *Auxiliary Climatological Stations* at which the observations are of the same kind as at the Normal Climatological Stations, but (*a*) less full, or (*b*) taken once a day only, or (*c*) taken at other than the recognised hours.

Table XV.

Number of Meteorological Stations in the British Empire and Mandated Territories.[1]

Country.	Area in 1,000 Sq. Miles.	No. of Meteorological Stations.					
		1st Order.	2nd Order.	3rd Order.	Unclassified.	Total.	Thousand Sq. Miles per Station.
Great Britain ..	89	9	347	177	13	546	0·2
Ireland[2]	32	2	25	12	—	39	0·8
Asia.							
British North Borneo ..	31	—	—	1	6	7	4·4
Ceylon	25	—	16	3	—	19	1·3
Cyprus	4	—	—	6	—	6	0·6
India[3]	1,766	3	3	241	—	247	7·1
Iraq	143	—	2	3	2	7	20·4
Federated Malay States and Straits Settlements	29	—	6	27	3	36	0·8
British New Guinea ..	90	—	—	18	—	18	5·0
Palestine ..	10	—	9	8	4	21	0·5
Africa.							
Cape Colony ..	277	2	60	19	8	89	3·1
Kenya ..	240	—	3	8	5	16	15·0
Tanganyika ..	373	5	40	10	1	56	6·7
Gambia	4	—	—	2	—	2	2·0
Gold Coast ..	92	—	—	13	3	16	5·8
Natal	35	1	—	20	1	22	1·6
Nigeria	335	—	—	25	3	28	12·0
Nyasaland ..	40	—	—	1	5	6	6·7
Southern Rhodesia	149	—	12	14	1	27	5·5
Sierra Leone ..	30	—	1	9	—	10	3·0
B. Somaliland ..	68	—	1	—	1	2	34·0
S. West Africa ..	322	—	5	—	7	12	26·8
Sudan	950	1	15	7	—	23	41·3
Swaziland ..	6·5	—	—	—	3	3	2·2
Transvaal ..	111	1	29	39	—	69	1·6
Uganda	110	—	2	12	2	16	6·9

Country.	Area in 1,000 Sq. Miles.	No. of Meteorological Stations.[1]					Thousand Sq. Miles per Station.
		1st Order.	2nd Order.	3rd Order.	Unclassified.	Total.	
America.							
Canada[4]	3,746	5	476	80	31	592	6·3
Newfoundland[5] and Labrador	40 / 511	—	15	3	2	20	—
Bahamas ..	5	—	6	—	1	7	0·7
Jamaica ..	4	—	1	12	—	13	0·3
Trinidad ..	2	—	—	1	1	2	1·0
British Guiana ..	89	—	1	4	1	6	14·8
Australasia.							
Australia ..	2,947	2	85	106	5	198	14·9
Tasmania ..	26	—	13	7	1	21	1·2
New Zealand ..	104	—	—	35	1	36	2·9

NOTES.

1. Areas are taken from the latest information in the "Encylopaedia Britannica;" the Meteorological Data from a Gazeteer compiled during the War by H. N. Dickson, D.Sc., of the Naval Intelligence Department, Admiralty. The list of stations is thus about ten years old. Only areas of more than 1,000 sq. miles have been included in the above table. The following smaller places may be cited: Mauritius, 720 sq. miles, 1, 1st Order; 4, 2nd Order; 1, 3rd Order; Seychelles, 156 sq. miles, 1, 2nd Order; 1, 3rd Order; Ascension, 38 sq. miles, 1 (unclassified); St. Helena (1 47 sq. miles station); Barbados, 166 sq. miles, 1, 2nd Order; 1, 3rd Order; Bermudas, 20 sq. miles, 1, 2nd Order; 2 unclassified; St. Kitts, 63 sq. miles, 1, 3rd Order; St. Vincent, 140 sq. miles, 2, 3rd Order.

2. Includes the Free State and Northern Ireland.

3. Includes Burmah, Bhotan and Assam.

4. Includes about 500,000 sq. miles in the Arctic regions.

5. No average figure has been given as it was not known how much of Labrador it would be appropriate to include.

As regards number of stations Table XV gives the number of 1st, 2nd and 3rd order stations in different parts of the Empire, and the average number of square miles per station in each territory. The list of stations is approximately ten years old, but no later one was available; nor was there obtainable a list of the many rainfall stations other than those of the 1st, 2nd and 3rd orders. In Great Britain there are between 5,000 and 6,000 rainfall stations; in India about 2,000.

The question of the adequacy of the number of meteorological stations in any area is of great interest, but has not, as far as the knowledge of the present writer goes, been very much studied; at any rate it is certain that the number of stations per square mile or its reciprocal is really quite an inadequate criterion, for in some regions of given size weather conditions will be almost uniform, in other regions of the same size they will vary greatly.

Perhaps the only adequate criterion is that any meteorological variate (say rainfall) in which we are interested should in any one station be capable of prediction from the values of the same variate at other neighbouring stations. For this purpose it is convenient if areas can be selected sufficiently small for the regression of the variate (say rainfall) on latitude, longitude and altitude to be effectively linear within each such area, and with a sufficient number of stations within the area to enable the regression line to be calculated with an assigned accuracy.

Altitude has been frequently neglected in the drawing of rainfall maps, a common procedure being to interpolate linearly between two observed stations to obtain a point on a given rainfall contour.

If, however, the regression line of rainfall on latitude, longitude and altitude has been calculated, and we assign a given value to the rainfall and the altitude we get a linear relation between latitude and longitude to which will correspond a straight line on the map. Where this straight line cuts the orographical contour corresponding to the altitude we shall obtain one or more points on the rainfall contour we wish to draw. Thus, a whole series of points on the same rainfall contour may be obtained by means of which the contours may be drawn, the altitude having been taken into consideration in determining each point.

Another advantage of such a method would be that, if desired, we could easily draw rainfall contours corrected to sea level. For this purpose the altitude would have its sea level value assigned to it in the equation and contours would be drawn through all places which would have the same rainfall, were they all at sea-level. At the same time the necessary correction per foot above sea-level would be given. The advantage of such an arrangement to a farmer in a narrow valley between high hills is obvious. Maps so constructed would show up clearly the effect of rainfall apart from altitude and not mimic the orographical features so closely as do, for instance, the rainfall maps of Great Britain.

An examination of the closeness of meteorological stations necessary to render this method possible both for rainfall and other meteorological variates in different parts of the Empire would form a research of great interest and utility.

CONCLUSION.

In this paper the writer has only been able to touch upon some aspects of a very wide subject. However, some account has been given of official methods of crop forecasting in three countries and of scientific studies whose object is the improvement of crop forecasting on the basis of meteorological factors. That official methods of forecasting can be improved by forecasts based on weather seems almost certain ; this must not, however, be taken to mean that in all cases satisfactory forecasts could be obtained on the basis of weather only, but at the worst, given adequate data, statistical technique is now competent to eliminate the effect of weather and leave the ground clear for the examination of any other factors which may be important.

But very considerable improvements will have to be made, particularly in crop data and to a less extent in meteorological data before the method reaches its maximum fruition. The value that the collection of such data would have, if applied to this purpose, to insurance, to trade, and to administration has been indicated.

In conclusion, I must express my indebtedness to Dr. R. A. Fisher for many valuable suggestions, to Mr. H. D. Vigor and Mr. W. R. Black, of the Ministry of Agriculture and Fisheries, for supplying me with material, and to Dr. H. H. Mann, Dr. H. Martin Leake and Mr. J. H. Field for information about India, and on one or two other points.

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